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THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

ART. X.—*Points in the Geological History of the islands* MAUI *and* OAHU; by JAMES D. DANA. With Plates III and IV.

THE subjects prominently illustrated by the islands Maui and Oahu are: the conditions of extinct volcanoes in different stages of degradation; the origin of long lines of precipice cutting deeply through the mountains; the extent and condition of one of the largest of craters at the period of extinction; and the relation of cinder and tufa cones to the parent volcano. The other islands of the group present facts bearing on these subjects, but the writer's knowledge of them is too imperfect for review in this place.

I. ISLAND OF MAUI.

The accompanying map, Plate 3, reduced from the recent large government map,* shows the general features of the island of Maui:

(1) The volcanic mountain of East Maui, Haleakala, 10,032 feet in height, having at summit, a crater 2500 feet in greatest depth and twenty-three miles in circuit.

* On this Plate, as on that of Hawaii in the last volume of this Journal, most of the lettering of the original map is omitted, with necessarily also minor details as to erosion and topography.

(2) The abrupt depression of Kipahulu, to the southeast of the summit, surveyed but not geologically studied, which looks as if it were the site of another great crater.

(3) The slopes of eastern Maui, little gullied by erosion, but most so on the side facing northeast—the windward side; and here the longest valleys scarcely reaching to the summit.

(4) The mountain of west Maui, a volcano in ruins, being profoundly cut up by valleys, and the original height reduced to 5788 feet as the maximum.

(5) The low intermont area of Maui, made of the united bases of the two volcanoes, but covered for the most part by the lava-flows of Haleakala, whose fires continued in action long after the western volcano was turned over, dead, to the dissecting elements; the width from north to south at the narrowest part, near the line reached by the lavas of Haleakala, about six miles, and the height at the survey station near its middle, 156 feet.

From my use of the maps of the Hawaiian government survey through the preceding memoir, and my frequent reference to them for facts about the volcanoes, craters and lava-flows, as well as the topography of the island, it has been apparent that they have been a very prominent basis for the conclusions presented. The government map of Maui has still greater geological importance; for Prof. Alexander, the surveyor-general, has made it, by his accurate work and his appreciation of the importance of details, a contribution to science of the highest value and interest. What I have to say of the extent, depth, form and discharge-ways of the great crater, of the heights and positions of cinder cones, and of the erosion of the mountains, should be put mainly to the credit of the map, which was Prof. Alexander's work not only in superintendence and geodetic measurement, but largely also in the details of the survey. The survey of the island, which is still in progress, reflects great credit on the Hawaiian people, and we trust it may be continued until in all parts complete. Every cone, or precipice, or fissure, terrace-level, or lava-stream located is a contribution to the history of the island and to physical and geological science.*

* I am, moreover, personally indebted to Prof. Alexander's kind providings, guidance and instructions for the success of my trip in 1887 (August 4 to 6) up Haleakala and into the crater, where a night was spent—an exceptionally brilliant night after a day of clear views from the slopes and the summit; and also for my excursion up Wailuku valley on western Maui.

I owed much also, while on the island, to the hospitality of Mr. Henry Baldwin of Haiku, Mr. Edward M. Walsh and Rev. Thomas Gulick of Paia, and Mr. Bailey and Rev. Mr. Bissell of Wailuku.

An excellent model of the island of Maui has been made by Prof. C. H. Hitchcock, who devoted much time to it during his recent visit to the Hawaiian Islands. The government map was the chief source of data for the details. The verti-

1. *East Maui.*

I. *The Mountain.*—The crater of Haleakala has been many times described, but first with a detailed map in illustration by Captain Wilkes. Captain Wilkes states that he is indebted for the map to his artist, Mr. Joseph Drayton;* and considering that it was from an artist's survey, not that of a surveying party with instruments, it is a remarkable piece of work. The expedition owes much to Mr. Drayton, not only for his excellent labors as draftsman in all departments at sea, but also, after his return, for his management of engravers, printers, etc., during the publication of the various Reports.

The mountain is usually ascended from Paia, a village on the north coast. The path (see map) passes Olinda and reaches the edge of the crater where the nearly vertical western wall bounding it is not less than 2500 feet in height. Thence it follows the summit southwestward to the southwest angle passing Pendulum Peak† on the borders of the crater just before reaching it. Here are three cinder cones, and the top of one is the culminating point of the mountain, 10,032 feet above tide. They stand at the head of a long line of cinder cones extending southwestward down the mountain to the sea; and near the sea at the foot of this line are three or four comparatively recent lava-streams, enough to illustrate the process of seashore extension by such sea-border outflows. From the southwest angle of the crater and the base of one of the three cinder cones, a cinder-made slope of rather easy grade descends into the crater, making a convenient place of descent; and thence the path continues eastward to the usual place of encampment, 4½ miles from the top.

2. *The two great discharge-ways of the crater.*—Besides its lofty walls and great area, the most remarkable features of the crater are the two openings, a northern and a southern, a mile to a mile and a half wide between precipitous walls of rock—the walls of the northern 2,000 feet and over, of the southern, 1,000 to 2,000 feet—through which poured the lava of probably the last of the great eruptions. The Kaupo lava-stream, the southern, has much the smoother surface, as if more recent; but the broader Koolau stream descended the *wind-*

cal height is increased four times, and the craters and valleys are thus strongly brought out. All such exaggerated relief maps, whether of a mountain or sea-basin, need a note of warning attached to prevent wrong conclusions as to slopes and heights; for the ratio of 4 to 1 instead of 1 to 1 changes a slope of 14° to one of 45°, a low to an acute cone. The light shading used on the map of Hawaii in the last volume of this Journal and here on that of Maui, is intended to bring out the idea as nearly as may be of a mean slope of 7 to 10 degrees.

* Wilkes's Narrative, vol. iv, p. 255. In the Exploring Expedition I had no chance to visit Maui, and saw it only from ship-board when passing it.

† The Pendulum station of Mr. E. D. Preston, of the Coast Survey, in 1887 This Journal, last volume, page 305.

ward slope, and the consequent erosion may have made all the difference.

3. *The Cinder-cones and Lavas at the bottom of the crater.*—Another striking feature of the crater is the group of red and gray cinder-cones which stand over the bottom, sixteen in number; the highest 900 feet above its base and all over 400, and yet looking small in the view from the summit of the great area. The sight to the northward, when half way to the bottom, comprising the northern discharge-way in the distance, the highest of the cinder-cones in the foreground, and beyond these and two other cones the broad stream of lava of the crater-floor as level apparently as a river, stretching away between precipices of more than 2,000 feet and then terminating in an even line at the limit of vision as if there began the plunge to the sea, is wonderfully like the real river of lava on its downward way.

The cinder-cones of the bottom were evidently the last work of the fires. The ashy surface of the cones is without a trace of erosion and thus bears no distinct marks of age. The slopes are mostly 25° to 30° and less, and hence they may have had the pitch diminished somewhat by the winds and rains and earthshocks, but there are no channelings by descending waters. The material is scoria in coarse fragments and sands, and though in part originally reddish and purplish, the red color has generally been deepened by oxidation from exposure.

Besides the scoria, there are on some of the cones, especially those toward the borders of the pit, numerous large blocks of gray, compact, scarcely vesiculated rock. Some of the masses about a cone near the place of descent measured over a hundred cubic feet. The masses must have been torn off from the throat of the volcano's conduit, this being the only conceivable source. They indicate therefore the action of vast projectile force at these isolated centers when the cones were in progress, and its continuation even to the close of the ejections; and they also are probable evidence of very rapid work in the cone-making. A few of the other cones were grayish in color as if from the abundance over their slopes of these projected grayish stones; but I was unable from want of time, to verify this supposition.

The cones stand, or appear to stand, on the rough, fresh-looking, scoriaceous lavas of the bottom, these lavas spreading away from beneath them. It was evident that the opened fissures or vents which gave exit to the cinders, first poured out the lavas; and then followed the cinder ejections as the fires declined and the liquid lavas of the vent became somewhat stiffened. The cinder material is proof of powerful projectile work; for the fragments of the exploding bubbles were thrown

upward, as the heights of the cones prove, many hundreds of feet—more than nine hundred to make the highest cone.

The fresh-looking lavas, occurring about the base of the more western of these cones, were found to continue eastward throughout the crater, with little change of features and with the same relation to the bases of the several cones, as if all were of one epoch of eruption—the epoch of the last outbreak of Haleakala; the lavas seemed to have come from the latest outflows of several subordinate vents, after the crater had made its great discharge through the two gateways down the mountains.

This scoriaceous lava of the crater contained in many places much augite and chrysolite in largish grains or crystals, being both augitophyric and chrysophyric.

4. *Lavas of the walls and summit.*—The lava of the walls was in part scoriaceous; but, where examined on the south and southwest sides, it was commonly a very compact, rather light gray variety of basalt, like that of the projected blocks about some of the cones. The layers of compact basalt had often one or more parallel planes of fine or coarse vesiculation, sometimes at intervals of one to three or four feet.

At one locality on the ascent of the mountain the solid gray rock had been found to be a convenient stone for stone implements of various kinds, and a large manufacture had apparently been carried on there; and yet near by, the lavas that were so solid had occasional planes of coarse vesiculation, each one to three or more inches thick. Pendulum Peak, near the summit, just north of the southwest corner of the crater (the place of descent) consists largely of this compact light-gray basalt, with rarely any vesiculation visible without the aid of a pocket lens.

This compact basalt or doleryte is a common rock also over the lower slopes toward Paia. It appears thus to be to a large extent the material of the older lavas; yet not only of the older. But at the summit on the west side, along the two miles passed over before reaching the place of descent, the compact variety of the basalt was rather the exception. There were large areas of the same scoriaceous lava that covers the bottom of the crater, and in some places it was equally augitophyric and chrysophyric, the augite in well-defined crystals. One of these areas was just north of Pendulum Peak; and a large region on the west border of the crater, looked as if successive streams of lava had recently flowed one over another, piling up layer on layer, so that by this means the surface for a breadth of a mile or more westward from the summit line had derived its unusual steepness of 15° to 16°. The lava-streams of the surface had the appearance of being overflows from the crater; as if the great pit had been full to the brim before the outbreak

and had poured out from time to time small streams like those of a full lava-lake in Kilauea. But they more probably came from fissures cut through to the summit at the time of the last or some one of the later eruptions.

The fact that lavas of the summit are so very chrysolitic, even at a height of nearly 10,000 feet, has an important bearing on the question as to the effect of high specific gravity in determining the distribution of materials in liquid lavas.

Crystals of augite and large grains of chrysolite are common in the loose material at the base of the cinder cones at the summit, near the place of descent, and colored glassy crystals of labradorite occur with them—facts first learned from Rev. T. L. Gulick after our return. These summit cones have the recent appearance and other features of those over the crater's bottom, and appear to be of the same series and time of origin; and the cinder-slope of that side of the crater was probably made in part from the ejections of these summit cones.

5. *The probable nature of the last eruption.*—The great discharge-ways of Haleakala, one to one and a half miles wide, with the walled valleys confining them, look as if the results of enormous rents of the mountain, made when the mountain emptied itself by the wide channels. But they may have been in existence before, and have been simply used for the last of the outflows. They are, nevertheless, evidence of rents at some time, and of a vast amount of removal of material some way—by subsidence, or otherwise. The height of the walls at the gaps, 2000 feet and over at the Koolau gap, and 1000 and over at the Kaupo, are a minimum measure of the amount of material removed. In my Exploring Expedition report I suggest that the mountain was fissured across along the lines of the two discharge-ways, and the eastern block shoved off a mile or two. But a subsidence of the masses that occupied them into caverns below, leaving the walls as fault planes, may be more probable. The abyss which received them in this case had been prepared during a long period of undermining through ejections. Still there is some reason to believe in the grander view of a subsidence of the whole eastern block, after the cross-fracturing. The island, as is seen on the map, is abruptly narrowed (instead of widened) at the spots where the Koolau and Kaupo streams reach the sea; and the part to the eastward is small, as if narrowed by such a subsidence. Moreover, the mean height of the eastern crater-wall is lower than that of the opposite or western by 500 to 1000 feet. A subsidence of 1000 feet increasing in amount to the eastward would account for the narrowing and for the very short eastern radius of the eccentric volcano. The question merits consideration.

The evidence that the lavas were discharged in both directions at once at the last eruption consists in the nearly uniform appearance of the fresh lavas over the bottom of the crater from one end to the other, and their continuing into and apparently being the streams that descend the Kaupo and Koolau discharge-ways. Mr. J. M. Alexander has remarked that the crater is probably a double one, a combination of two great craters, as Mokuaweoweo at the summit of Mt. Loa is compound in structure. This is no doubt historically true; but at the latest of the eruptions there was probably one action over the whole, the distinction for the time obliterated.

The period of the last summit eruption is unknown. I learn from Mr. Bailey of Wailuku, Maui, that, according to an island tradition, a *lateral* eruption of the mountain occurred about 150 years since in the district of Honuaaula of the southern part of East Maui, at an elevation above the sea probably of about 400 feet.

6. *Activity of the Crater ending in Cinder-ejections.*—The origin of the *crater* of Haleakala needs, I believe, no explanation beyond that given in the remarks on the origin of craters generally: that a volcanic crater and the mountain containing it commence to form together about an opened vent which discharges both vapors and lavas; that the crater is a result of the projectile action and the discharge of material from below, and generally also of subsidence into the cavity which is made by the discharge; and that it does not become closed before the central vent ceases to discharge, and commonly is not then closed.*

Haleakala is an example of a basaltic volcano which reached its end, through declining fires, in cinder ejections; but it left its great crater open, and 2000 to 2500 feet deep, with the greater part of the bottom free from the cinders notwithstanding the amount discharged. The latest down-plunge or subsidence by which the vast pit and perhaps also its discharge-ways were made, may therefore have filled full the empty subterranean chambers which former outflows had produced, and left the mountain solid instead of hollow. Mt. Kea on Hawaii, 13,805 feet in height, also ended its work with cinder eruptions; but the ejected material of lavas and cinders obliterated so far the old crater that no visitor of the region has yet found traces of its former limits. Whether Mt. Kea is a hollow mountain or not remains to be ascertained.

Since the above was written, the results of the pendulum investigations of Mr. E. D. Preston at the summit of Haleakala have been made known in a paper published in the number of

* This J., xxxv, 33, Jan. 1888. The view is the same published in my Exploring Expedition Report, 40 years since.

this Journal for November last,* and have afforded unexpected evidence on these doubtful points. They have led him to the important conclusion that "the density of the mountain is at least equal to its surface density," and that, therefore, unlike some results obtained on the continents, "it is a solid mountain," so that the interior must have been left filled by the subsidence of rock that made the great crater at the summit. He states also that "the zenith telescope observations at the foot of the mountain indicate the same fact."

Mr. Preston states further that at Kohala, on the *north* coast of the island Hawaii, the plumb-line deflections were half a minute *southward*, which, he adds, is well explained by the position to the southward of all the great mountains of Hawaii. He records also that at Hilo, on the *east* coast, the deflection was a fourth of a minute *to the northward*. Mr. Preston remarks that "there is no explanation" of this result at Hilo "unless we assume that the south side of Hawaii, where the volcanoes are active, is much less dense than the north side where the fires have been slumbering for centuries." But to the north of Hilo is a long reach of ocean, the coast of Hawaii there trending northwest; the summit of Mt. Kea, 13,805 feet high, is 25 miles distant and bears N. 75° W.; and that of Mt. Loa, 13,675 feet high, is 35 miles distant and bears S. 63° W.; and the center of gravity of the combined mass (the lowest level over 5000 feet) bears probably a little south of due west. It appears, hence, that we have here evidence that Kea is like Loa, *not* solid; that it is a hollow mountain, as inferred above from the absence of a summit crater; but Mr. Preston is probably right in his inference that Mt. Loa is the more cavernous of the two. Additional plumb-line and pendulum observations are, however, much to be desired.

2. *West Maui.*

West Maui has lost the original slopes of its great cone and its crater through erosion. It has been supposed that remains of three great craters may be distinguished in the mountains: the largest at the head of Wailuku or Iao valley on the north border of which rises the highest peak, Puu Kukui, 5788 feet high; another in the less deep valley of Waihee, just north of this; and a third at the head of the Olowaiu valley, to the south.

I examined only the Wailuku valley, the largest of the three, —so named from the village on the coast near its entrance. The valley is a deep cut into the mountains, remarkably grand in its precipitous walls with thin crested summits. It widens

* Vol. xxxvi, 305.

somewhat toward its head, and in this upper part an extensive plateau occupies the center. The torrent of the valley is here divided between two tributaries, one running either side of the plateau. The height and rather bold sides of the plateau at the head of the valley, and its size and position, taken in connection with its location near the center of the mountain range, appear to make it pretty certain that the plateau represents the floor, or rather what is left of the central area, of the great crater. I looked for the edges of lava streams in the enclosing walls in order to make out their pitch and the thickness of the beds. But dense vegetation so covers everything that distant views are of no geological value, and one day's excursion was not sufficient for a climb of the heights.

As to the former crater condition of the other two valleys mentioned, I know nothing from personal observation. The idea of their having been craters is based on the size, depth, and boldness of the walls and the ampitheater-like head. But these features are common results of denudation in old volcanic islands, and therefore, in the question here considered I give them little weight.

3. *The Eccentric form of the Maui Volcanoes.*

The map of Maui illustrates a Hawaiian feature of volcanic mountains which may be common in other regions. The chief crater of the mountain is not at its center. In Haleakala the ratio of the radii east and west of the crater is 2 : 3; and in West Maui, 8 : 11. The shorter radius is to the south-southeast of the crater in one and to the southeast in the other.

In Hawaii it is not easy to mark off the true base of Mt. Loa. But we have the fact that in both the summit crater and Kilauea, the form is oblong, and each has its intenser activity in the more southern portion—the south-southwestern in one, and the southwestern in the other. The effect is not due to the to the winds, for the mountains consist almost solely of lava-streams.

4. *Drift-made ridge of consolidated coral sand.*

The positions of the high ridge of consolidated coral sand of Wailuku are indicated on the map. Whether proof of elevation or not is yet undecided. I was informed that the sands are at the present time drifted by the trade-winds to the farther inland limit of these ridges and over their surfaces—a fact which seems to show that present conditions are sufficient for their production.

II. Island of Oahu.

From the map of Oahu, Plate 4, it is apparent that the island (*a*) consists of two eroded mountain regions, an eastern and a western, separated by a plain sloping gently downward to the opposite coasts and upward toward the eastern mountains. A more remarkable feature (*b*) is the long and high precipice fronting northeastward, and thus facing the tradewinds. Besides these characteristics (*c*), there are lateral or subordinate volcanic cones on the sea-border, of which Diamond Head and its companions, Punchbowl, and the Koko Head craters on the eastern cape (Plate 4, figs. 1, 2, 3), are examples. The island is the only one of the group that has (*d*) a nearly continuous coral reef fringing the shores. It owes to this reef the harbor of Honolulu, the one good harbor of the group, and also the possibility of a much larger and better one at Pearl River, seven miles west of Honolulu; the cutting of a channel through the reef is all that is needed, as has long been recognized, to make these capacious inner waters available for shipping*. Another interesting feature (*e*) is the existence of an *elevated* coral reef on the borders of the island, having its inner limits approximately indicated on the map by a dotted line.

The facts on which the following account of the island is based and the views deduced from them are for the most part contained in my Expedition Geological Report. The visit in 1840 gave me nearly a month for study, which was industriously employed in excursions over and around the island. The accompanying map, on Plate 4, differs little, excepting in improvement in outline and topography, from the colored geological map of my Report, and the outline of the elevated coral reef and its coral rock and sand bluffs are copied from it. The view of the tufa cones on the same plate are simply new drawings from some of my old sketches. For fuller particulars and some views not reproduced—as those of Kaneohe Point and Aliapaakai, I refer to the Report. My recent visit (in 1887) gave me an opportunity for another excursion around a large part of the island (taken with President Merritt), and

* Honolulu, the capital of the Hawaiian Kingdom, was a collection of thatched huts in 1840, with exceptions only in a Custom House, an unfinished coral-rock church, and a few dwellings of civilized aspect. To-day it is city-like in its houses, its streets electrically lighted, its public squares, large Hospital grounds, spacious Government buildings—among them a palace good enough for any potentate—and its excellent hotel; and, through the addition of groves and avenues of introduced palms and tropical trees (some of which are always in flower or fruit) it is fast becoming a place of ideal beauty. Honolulu is the center of all the island activities, including inter-island navigation. It is not out of place to repeat here that steamers start every week or two for Hawaii and Kilauea—one route by Hilo to Keauhou, and thence up by horseback and wheels, the other by Punaluu on the south coast, where there is a good hotel and a carriage road all the way to the volcano. A carriage road from Hilo to Kilauea is in prospect.

for further explorations, refreshing old memories and adding new facts; and this return to the subject affords an occasion also for reconsidering former conclusions.

1. *Features, structure, and origin of Oahu.*

1. *General features; Contrast with the island of Maui.*—Like Maui, Oahu is in origin a volcano-doublet—that is, as regards rock-structure, it was the united work of two great volcanoes, a western and an eastern. But unlike Maui, its two volcanic cones or domes have suffered so great loss that the position of either crater is wholly a matter of conjecture.

A large part of the loss Oahu has suffered is due to denuding agencies. East Maui, as the map on Plate 3 illustrates, has lost in this way comparatively little of its original evenness of surface owing to the recency of its extinction. Its windward gorges are narrow, and only shallow gulches occur over the leeward surface. The ratio of its diameters at base, 1:1·3, is probably very near the original ratio. West Maui is profoundly gorged on all sides and most deeply so to windward, illustrating results of longer wear than East Maui has had. But something of the old slopes remain, and in the base we have still the ratio of its old diameters, 1:1·4, with the outline little indented. The double lesson is taught: (1) what denudation from descending waters does to a volcanic cone 5° to 10° in slope in the region of the trades; (2) what, on the contrary, the sea cannot do, no encroachments of note existing to attest to its power, notwithstanding the length of the era of denudation.

Oahu resembles Maui in having the western mountain-cone the most time-worn and the smaller in area, but here the likeness ends. Both of its mountains are deeply eroded. Further, East Oahu has only part of its old slopes left. They remain only on its southern, western and northern sides; the northeastern are cut off by the great precipice, twenty miles long, which is made for the most part of the edges of the lava-streams that slope southward and westward. The sharp-edged serrated ridge, making the summit of the precipice, is from 1000 to 3000 feet in height, and at its northeastern base, from Kualoa eastward, there is in general only a narrow strip of low land with low hills, the width but three or four miles except in the Kaneohe peninsula. The precipice continues beyond Kualoa northwestward, but not the low land at its base.

These features have occasioned peculiarities in the results of denudation on East Oahu. The leeward or south and southwestern sides have long and deep valleys, some of them heading in broad amphitheaters under the crested mountain ridge. The windward side, along the 20-mile precipice, on the contrary, has buttresses and shallow alcoves, with a but-

tress here and there lengthening out into a ridge; and only farther northwest, beyond Kualoa, are there the longer valleys or gorges and ridges and the mountain architecture characteristic of deeply worn windward slopes.

The only broad valley of the leeward or south and southwestward slope that is continued upward with gradual ascent to the very edge of the precipice is that of Nuuanu, behind the city of Honolulu. It is the valley to the left in fig. 2 on Plate 4. Six miles up it ends in the "*pali*," or precipice, and overlooks the northeastern sea-border plains and hills. The height of the "pali" is only 1207 feet above the sea; but on either side are the highest peaks of the range, Konahuanui 3105 feet in height, and Lanihuli, 2775 feet.

Great denudation on the *leeward* side of an island is an exception to the usual rule. It is a consequence, on Oahu, of the sharp-crested 20-mile precipice. The trade winds become chilled on striking the summit of the precipice and ready, therefore, to drop their moisture; but as they are moving on, they get beyond the summit before much of the moisture falls, and so the *leeward* slopes receive the water. In the upper part of the Nuuanu valley, within two miles of the *pali*, 132 inches of rain fall a year, and nearly 100 inches less than this at Honolulu, although brief sprinklings occur almost daily over the city. Konahuanui and Lanihuli, as seen from Honolulu are generally under clouds, but from Kaneohe they are usually uncovered.

A nearly similar condition exists in West Maui, owing to the thinness of the rocky walls at the head of its great valleys. Very broad valleys are consequently made on the leeward side, as in Oahu; but these valleys soon end below in a slender gulch, which may be, for the most of the year a "dry run;" the excessive dryness and heat of the lower plains evaporating powerfully and supplying no water.

2. *Orographic condition of East Oahu.*—From the facts mentioned, it appears to be plain that the chief structural difference between East Oahu and East Maui is that the latter is a whole volcanic mountain, and the former a piece of one. By some means the Oahu mountain-cone or dome has lost, as I concluded in 1840, a large piece from its mass—all that once existed northeast of the 20-mile precipice. The size of the lost piece it is not easy to determine. The lava streams of the leeward slopes, which dip away from the precipice mostly at an angle of 3° to 5° (as seen in the intersecting valleys), must have come from some point or points beyond it to the northeastward.

Following the leeward slopes around westward and northward we find all pointing upward toward the higher part of

the mountains, as if the source were somewhere in that direction; but just where, remains in doubt; and it may be even questioned whether there may not have been two or more great craters along the line.

No point or region has a more reasonable claim for consideration in this respect than the head of Nuuanu valley. In situation and width, and the features at its head, it is just what should be looked for in a great discharge-way. On my recent visit I sought for facts bearing on the question and found the dip of the beds to diminish from 3° to 1° toward the top, and at the "pali," the beds were very nearly or quite horizontal. This is favorable to the conclusion that the crater was either at its head or near by it, just beyond the precipice. The low land below, over the Kaneohe peninsula and between this peninsula and the "pali," is a region of tufa hills and other small cones, unlike any part elsewhere of the north or northeast coast. In addition, at the head of Nuuanu valley, very near the top of the "pali," there are the remains of a red cinder cone. Besides this, on descending the steep "pali" by the path, there is to the east of the path a long broad slope, 35° to 40° in angle, consisting of reddish layers of volcanic cinders, scoria, earth and stones—indicating cinder ejection from some point above.

It is therefore most probable that the center of volcanic activity for East Oahu was in the vicinity of the "pali," above the low region a little to the northeast of it. The cinder cones above mentioned may have been results of the last efforts of the declining fires, like those of Haleakala and Mt. Kea.

In 1840, I was led to locate the central crater on the Kaneohe peninsula, because the head of the "pali" was so near the southern foot of the mountain; I thought it must have been farther off. But the fact that the volcanic mountains of East and West Maui are eccentric in ground-plan, and that the same feature quite certainly characterized this Oahu cone, makes the position near the "pali" the most probable. In Haleakala the center of the crater is only six miles from the southern shore; and this distance in the Oahu crater, on the above supposition, would be about seven miles. The idea of an eccentric cone fourteen or fifteen miles in the transverse diameter through the crater is thus strongly favored. On further comparison with Haleakala, we find that the part of the longer diameter of the mountains which lies northwest of the center of the crater is about 19 miles in length on Maui, and on Oahu it would be nearly 25 miles. The small dip of 1° to 3° prevails widely about the mountains at Kualoa point and to the northward, as well as in the upper part of the Manoa valley, west of the Nuuanu; and from this it may be inferred

that the East Oahu mountain was a dome, like Mt. Loa, rather than a cone like Haleakala. The existence of one or more craters west of the "pali" has been urged, and is possible. I know of no special facts sustaining it. The amphitheater at the head of Manoa valley is referred to by Mr. Brigham as probably the site of a crater; but I was more inclined from my examination to make it an amphitheater of erosion.

3. *Origin of the long precipice on Oahu.*—The long precipice of East Oahu has been attributed to erosion. But I have found no evidence that such transverse walls are legitimate effects of erosion, either fluvial or marine. As illustrated on Maui (p. 91), the sea works with extreme slowness in battering lava-cliffs, and cannot work at all below the limit of forceful wave-action—a level not twenty feet beneath the surface. Fluvial action makes long valleys in the long descending mountains and capes which the sea is incapable of obliterating. Land waters have done grand work in alcoving the long precipice, and carving battlements and temples out of the rocky piles that were left, as is well exhibited in the Kualoa bluffs, while the sea has not even scraped away the small tufa cones on its borders. It might be said that the cones of Kaneohe and the "pali" have been made since the era of erosion; but this disconnects their origin by a very long era from the period of activity in the crater.

Another view with regard to the origin of the precipice is that of my Expedition Report, namely that it was made by a profound fracturing of the mountain-dome across from southeast to northwest, and a drop-down of part of the outer or eastern section. The line of fracture was irregular—the course rather of a series of fractures; and subsidences of varying extent may have taken place along the line, becoming smaller to the northwest, where high ridges are left between the precipice and the coast. The amount of displacement was not less than the height of Konahuanui, 3105 feet, and probably much exceeded this.

Great catastrophic subsidences are not uncommon in volcanic regions. In the account of Maui and its crater the fact of a subsidence not less than 2500 feet, accompanying and following some one of its eruptions, appears to be placed beyond doubt. Hawaii has plain evidences about its crater of subsidences hundreds of feet in amount of displacement if not thousands; and there are high precipices, like that at Kealakekua Bay, for which there appears to be no other probable source of origin.

The small western island of the Hawaiian group, Niihau, has a bold precipice as its eastern face, 1500 to 1800 feet in height above the sea, and the lava-streams of the island pitch

from the precipice to the westward, showing that the streams flowed from a point to the eastward, and that a large piece, perhaps the larger part, of an old volcano has disappeared. Kauai, north of Niihau, has its Napali cliff, a dozen miles long, along its southwest side, in a line with the Niihau cliff. Molokai, to the east of Oahu, was once, as its lava-streams prove, a doublet of volcanoes, like Maui; but it has been shaved down to a strip of land 35 miles long, and not a fifth of this in mean width. The eastern part has an alcoved precipice facing the north, which rises to a height of 2500 feet above the sea. It encloses a strip of land along the sea shore, and on this spot, thus walled in, it has been found convenient to locate the Leper quarantine-ground of the islands. Lanai, a narrow island south of Molokai about 20 miles long, has a bold front to the south and gradual slopes from it in other directions. Thus such precipices are rather the rule in the Hawaiian group; and if seashore erosion is not the origin—as an island like Tahiti, with its profound radiating gorges as a result of fluvial action and its non-gorged coast, appears to show*—fractures and subsidence must be.

A great volcano is a disgorger of lava in vast floods and so it makes its mountain; and it may make also empty cavities at the same time and as a consequence. As long as the ascensive force keeps the liquid lava-column of the active volcano fully up to the summit crater, the mountain may have only local cavities. But whenever a great discharge takes place, a coequal cavity may result; and if the discharge is from fissures at the base of the cone, 15,000 to 18,000 feet below the sea level (not a greater depth than exists in the neighboring seas) an enormous cavity may be left, which only the renewed action of the ascensive force would fill. If the mountain *then* became extinct with no return of the liquid, it would be a hollow mountain; and the greatest of subsidences which the Hawaiian facts seem to indicate, are small compared with the possible consequences of such a condition.

4. *The Tufa and other Lateral cones of East Oahu.*—Several of these cones, as already stated, are represented on Plate 4.

Punchbowl, fig. 2, stands on the northern border of Honolulu (at P on the map).† Its highest point is 498 feet above tide-level. The tufa of the beds constituting it, though rather feebly consolidated, is quarried on the west side of the cone, and specimens may there be conveniently obtained. It is a yellow to brown, in part resin-lustered, palagonite-like rock, bearing evidence in its constitution and in the dip of the beds,

* This Journal, xxxii, 247, 1886.

† The sketch was taken in 1840 from the deck of the ship Peacock as she lay in the harbor. The native huts at its foot are omitted.

that mud-making warm waters were concerned in the deposition; and its being of brown, in place of red, color, is probable evidence that the temperature of the water was below 200° F.

Diamond Hill, fig. 1, makes the prominent cape east of the city; its bold southern brow has a height of 761 feet above the sea at its base. It is, like Punchbowl, a fine example of the typical tufa-cone in its broad and shallow, saucer-shaped crater, with the stratification parallel to the bottom of the saucer and to the original outer slope. These slopes have become deeply trenched, as the view shows, by descending waters; and since 1840, the southern brow has lost something of its boldness. Two other cones stand in a line to the north of it, the first, a place of lava outflow. The three vents appear to be situated on a single line of fracture.

The Koko Head tufa-cones are situated at the east extremity of the island. The view (fig. 3) was taken from the eastward at sea. The larger or more northern of the two cones is much denuded inside and out. The other low cone, situated on the Point, is worn to its center by the sea, and has thereby been made to exhibit to the passing vessel (as it goes from or toward Honolulu) the dip of its tufa beds inward and outward, and thereby the true structure of such a cone.

Artesian borings on Oahu afford some facts bearing on the history of Diamond Head and Punchbowl. The borings were made by Mr. J. A. McCandless of Honolulu, and records of a number of them have been received from him through Prof. W. D. Alexander.

The following section is from James Campbell's well, at the west foot of Diamond Head, not far from the sea-level.

	Thickness.	Depth.
Gravel and beach sand	50 feet	----
Tufa like that of Diamond Head	270	320 feet
HARD CORAL ROCK, like marble	**505**	**825**
Dark brown clay	75	900
Washed gravel	25	925
Deep red clay	95	1020
SOFT WHITE CORAL	**28**	**1048**
Soapstone-like rock	20	1068
Brown clay and BROKEN CORAL	110	1178
Hard blue lava	45	1223
Black and red clay	28	1251
Brown lava	249	1500

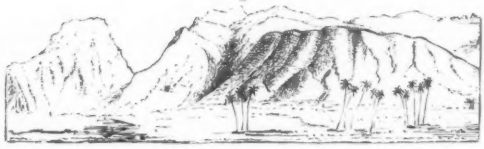
The well went down 1178 feet before reaching the solid lava of the bottom. In its upper part it passed through 270 feet of tufa, indicating that the tufa-cone extended below the sea-level to this depth, and therefore had a total height of over 1000 feet. Below the tufa, between the 320-foot and 825-foot

MAUI
FROM THE
GOVERNMENT MAP
5 10
miles
Honolua
Napili
Kahoma
Lahaina
Olowalu Mt.
Kahului
Paia
Hana
Makena
Kaupo
Nuu
Hamakua
Olinda
Waikamoi
Haleakala
Kolekole
Kaupo Gap
Hana
Makawao
Kula
Waiohuli
Honuaula
Waihee
Wailuku
Iao Valley
Iao Needle
Waikapu
Waihee
Kahakuloa
Honokahua
Honokohau
Honolua
Kahakuloa Head
Kahului
Makena
Kaupo
Nuu
Hana
Olinda
Haleakala
Kolekole
Kaupo Gap
Waikamoi
Makawao
Kula
Waiohuli
Honuaula
Waihee
Wailuku
Iao Valley
Iao Needle
Waikapu
Kahakuloa
Honokahua
Honokohau
Honolua
Kahakuloa Head
21'
55'
50'
40'
20'
35'
156° 5'
10'
15'
20'
25'
156° 30'
40'
35'

1

c b a

2



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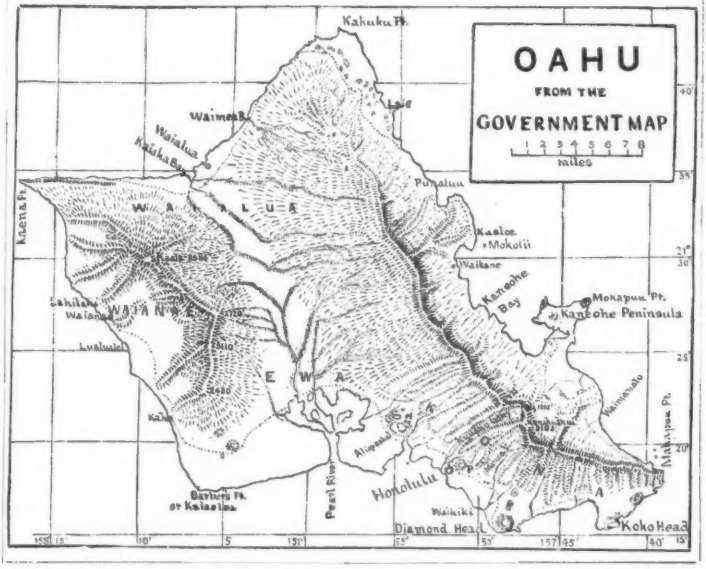


1. The volcanic cones: *a*, Diamond Head, or Leahi; *b*, Kaimuki, or Telegraph Hill, and *c*, Maaumae. 2. Punchbowl, or Puowaina, with Nuuanu valley to the left, and the peaks Konahuanui and Lunahili, right and left of the pali. 3. The Koko Head craters.

levels, there are 505 feet of *hard coral rock;* and then on the 1045-foot level, a 28-foot layer of *soft white coral* and at a greater depth, brown clay and broken coral. As the well is close by the west foot of the Head and passes through so much of its tufa, it is quite certain that the 505-foot stratum of limestone was made before the tufa-eruption; and that the beds underneath it mark earlier conditions over the site.

As regards a supply of fresh water the well was a failure—an exception to the usual experience. The water came up salt and a much stronger brine than sea-water. It was under some pressure, as it stood a foot above the level of surface wells near by.

Other borings have been made in Waikiki—the sea-border district just west of Diamond Head. The section afforded by the deepest of the Waikiki wells is here inserted for comparison. It is that of the King's well, No. 2—about half a mile west of Diamond Hill and 350 yards from the seashore.

	Thickness.	Depth.
Sand and coral	38 feet	----
WHITE CORAL ROCK	**22**	**60**
Yellow sand	43	103
Hard lava	47	150
WHITE CORAL ROCK	**110**	**260**
Blue clay	25	285
Tough clay and CORAL	65	350
Blue clay	30	380
HARD CORAL ROCK	**40**	**420**
SOFT CORAL	**30**	**450**
Tough clay	5	455
WHITE CORAL ROCK	**40**	**495**
Tough clay	30	525
WHITE CORAL ROCK	**100**	**625**
Tough clay	5	630
CORAL and clay	**70**	**700**
Tough clay	28	728
Black sand	2	730
Lava	120	850

In this well, the upper 320 feet probably correspond approximately to the upper tufa-made portion of the preceding. It is remarkable that tufa is wholly absent, although the distance from the active vent was so small; but this is accounted for by the direction of the trade winds, which would have carried the ejected material seaward—the direction in which the hill is elongated. Moreover the tufa-cone although 1000 feet high may have been thrown up in a single year or less. Instead of tufa for the upper part, there are, underneath 38 feet of sand and

coral, 22 feet of white coral rock; 110 feet more of the coral rock above the 260-foot level, and 65 feet of "tough clay and coral" next above the 350-foot level. Further, beginning with the 385-foot level, coral rock is continued to the 700-foot level, or for 315 feet, with the exception of 40 feet of clay divided between three layers; and this 315-foot layer of limestone appears to correspond to the 505-foot layer between 320 and 825 feet in the other section. The solid lava-stream of the bottom of the well was reached at 730 feet. The amount of water obtained proved that the lava-stream was one of those from the mountain. It is overlaid by 2 feet of volcanic sand and 28 of tough clay, the sand serving to contain the water and the clay to confine it, conditions suited to make the well a success.

In these sections the intercalated beds of so-called "clay" vary widely in position and thickness, and appear to be, in general, local deposits from mountain streams, or tufa deposits from one source or another. In another boring in Waikiki, a bottom of solid lava was reached at 375 feet; and in a third, Goo Kim's well, at 475 feet. The former had an intercalated lava-stream at a depth of 206 feet, and the other at 150 feet. In Goo Kim's well, which was nearly a mile from the seashore, there were 26 feet of coral rock above the 150-foot level, and 194 feet of coral rock above the 430-foot level but with two intercalations of a 20-foot layer of "clay" in the stratum. The facts as to the varying levels of the "clay" beds and the intercalation of lava-streams show what accidents the living species of the sea and its reefs were exposed to. They make the existence of a *continuous* 505-foot stratum of coral limestone underneath the tufa of Diamond Head the more remarkable.

The artesian wells made within the limits of the city of Honolulu might be expected to throw light on the history of Punchbowl.

1. A well in "Thomas Square," just south of Punchbowl, afforded the following section.

Soil 6 feet, with 6 of black sand and "clay" 4	16 ft.	...
White coral rock	200	216 ft.
Brown clay	44	260
Coral rock	10	270
Brown clay	60	330
White coral rock	50	380
Brown clay	80	460
Bed rock or lava, penetrated	49	509

2. In "Mr. Ward's well," below Thomas Square, on King street, there were at the top 15 feet of loam and sand, then 180 feet of "hard coral rock," carrying the depth to 195 feet; again 24 feet of coral and shells above the 219-foot level; and

then, underneath 109 feet of "yellow clay" which may be Punchbowl tufa, 23 feet of coral rock above the 393-foot level, and 107 feet of white and yellow sand below it; with the bottom lava at 508 feet covered by 4 feet of quicksand. An abundant flow of water was obtained.

3. South of the last, in the "Kewalo well," begun near the sea-level, beneath 6 feet of black volcanic sand, there were 50 feet of coral rock over a 40-foot layer of hard lava; then 190 feet of coral, divided in two by an intercalated 30-foot layer of "clay," over the 350-foot level; with the bottom lava-bed at 620 feet.

4. Section from a well in the Palace yard:

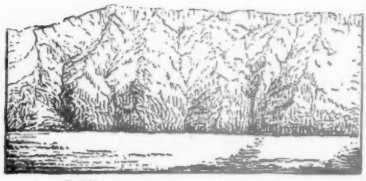
Soil 4 feet, black sand 4	8 feet.	
Coral rock	64	72 feet.
Hard lava	6	78
White coral rock	60	138
Clay	240	378
Coral rock	75	452
Clay and gravel	254	707
Lava or bed rock penetrated	55	762

Of the above sections 1, 2 and 3 have a thick bed of clay on the 260-foot to 280-foot level; 1, 2 and 4 on the 330-foot, 370-foot and 378-foot levels; 1 and 2 and 3 on 460-foot, 500-foot and 535-foot levels; and No. 4, a layer 254 feet thick on the 707-foot level or the bottom rock. It is possible that one or more of these of "clay" may be decomposed tufa of Punchbowl origin. But to refer all to this source would make the period of eruption of very improbable length. The "black sand" below the soil in Honolulu is naturally referred to this source. But more investigation is required for a decision. There is no evidence that Diamond Head and Punchbowl were of simultaneous origin.

5. *West Oahu.*—The mountains of West Oahu cover at the present time a much smaller area than those of East Oahu. Their original dimensions we have no data for estimating. The highest peak, Kaala, in the northeast part of the group of summits, has a height, according to the government survey, of 3586 feet—which is 681 feet greater than that of Konahuinui; and besides this, there are, in the southeastern part, peaks of 3105 and 3110 feet. These elevations, and the deep and open valleys divided off by sharp ridges, are sufficient evidence that the mountain range is but a small remnant of the once great volcanic mountain, probably a loftier mountain than that of East Oahu. Denudation has had a far longer time for its dissecting work, and has done much to diminish the area it covers. Whether great loss has resulted also from subsidence is not ascertained.

The fact that the volcano of East Oahu was in full action long after the extension of the western cone, is shown (as I first observed in 1840 and again in 1887) by the encroachment of the eastern lava-streams over its base, and the burial in part of the valleys. The accompanying sketch is a view, looking westward from the plain made by the encroaching lavas, showing how the lavas dammed up the already made valleys of West Oahu, and forced the drainage waters to take a north or south direction, nearly parallel with the base of the mountain, in order to reach the sea. The courses of these streams are shown on the map. The depth of burial by the East Oahu lavas was probably some hundreds of feet.

1.



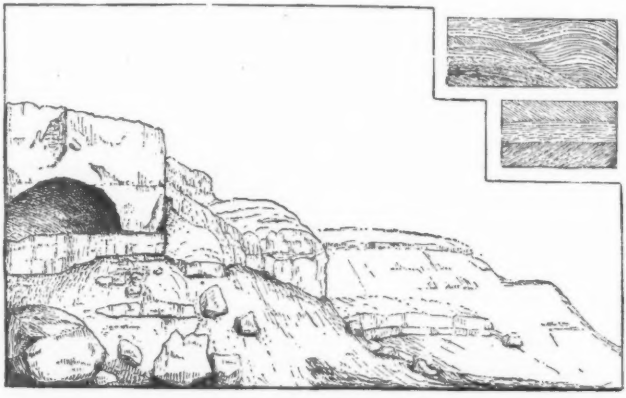
2. *Evidence of recent change of level.*

1. *Elevation.*—Evidence of recent upward change of level is afforded by the elevated coral reef along the sea-border. The dotted line on the map (Plate 4) has already been pointed to as approximately the inner limit of the raised reef; the small dotted areas about Kahuku Point, the prominent north cape of the island, and in Laie, the district next southeastward, besides others west of Waimanalo, are the positions of hills or bluffs made of the reef rock and consolidated drift sands. The rock is in some parts a beautiful white, fine-grained building stone; but generally it has sudden transitions in texture and firmness, and much of it is a consolidated mass of broken corals, or else of standing corals made compact or nearly so with coral sand. Along southern or southwestern Oahu the height of the reef is fifteen to thirty feet; and I estimated the amount of elevation indicated by it in 1840 at 30 to 40 feet.

At the Kahuku bluffs, which I visited anew in 1887 (see figure 2), the solid coral reef rock extends up in some places to a height by estimate of fifty to sixty feet above tide level; and this is surmounted by drift-sand rock, made of beach coral sands that were drifted into hills on the coast when the reef-rock was submerged, adding twenty feet or more to the height. There are large caverns in the bluffs, which are mostly within the upper layer of the coral reef-rock and have the drift-sand rock as the roof. In the sketch, a faint horizontal line may be seen passing by the top of the cavern; it separates the beds of different origin. The coral reef-rock consists mostly of cemented masses and branches of corals of the kinds common in

the modern reef, and also has often the corals in the positions of growth. But the wind-drift beds show the quaquaversal or variously-striking dip common in wind-made drifts, as represented in the two sections below.

2.



Kahuku bluffs of coral rock and drift-sands, with two sections of the drift-sand rock.

The change of level along northern Oahu, according to the facts from Kahuku, appears to have been at least sixty feet, or twenty feet greater than on its southern side. Even with an accurate measurement of the height of the reef-rock about Oahu the amount of elevation would remain doubtful because the coral reefs off the island are at present nowhere up to low-tide level; and this may or may not have been the fact before the change of level took place.

The surface of the elevated reef of Oahu is exceedingly uneven from unequal construction and erosion, and its interior has in some places large and winding caverns, so that an overlying formation, were there one, would afford an example of *unconformability by denudation.* It is obvious that with greater elevation, the unevenness would be as much greater, large enough to get the credit, perhaps, of representing an interval of many thousands of years, although results of the "modern" period in geology. Denudation works rapidly among limestones and especially so when the limestones have just left the water, with the usual irregularities of upper surface and texture.

2. *Subsidence.*—A gradual subsidence of the island is apparently indicated by the coral reefs, through the depth to which they have been found to extend in Artesian borings. In these borings, described on page 96, a depth of 700 to 800 feet was

found for the coral rock, and more than 1,000 for broken corals; and over 700 is reported by Mr. McCandless from a well in the Eua district, about five miles west of Honolulu. The facts lead to the inference that the subsidence amounted to at least 800 feet, and that it corresponds to the coral-reef subsidence which Darwin's theory requires. Mr. McCandless informed me that fragments of corals like those of the modern reefs were brought up from the various levels.

This evidence of subsidence to the amount stated is not, however, complete. Doubt remains because the corals brought up in fragments have not been examined by any one competent to decide on their actual identity with existing species; I could not find that any of them had been preserved. The importance of their preservation and careful study is now understood, and we may hope before long to have the doubt removed. As the case stands, the *probability* is that the limestone is to the bottom true coral-reef rock and that the depth to which it extends is, therefore, a measure of actual subsidence.

Darwin's Coral Island theory.—In the above statements the present condition of Darwin's theory of Coral Islands, is fully and fairly recognized. Much has been recently written about the theory's having been set aside or proved to be without foundation. But in truth, no facts have been published that prove the theory false, or set aside the arguments in its favor. The facts and arguments from Tahiti brought out by Mr. Murray I have shown, in my review of the subject in this Journal in 1885* (published also at the same time in the London Philosophical Magazine), to have no weight and more than this, to sustain Darwin's theory, instead of opposing it. The idea of the excavation of the lagoon-basins of coral islands by sea-waters I have also proved in the same paper to be not a possibility.

The only suggestion of real importance that has been presented is not against Darwin's explanation, but simply in favor of a possible substitute. Mr. A. Agassiz and others have suggested that deep-sea organisms may build up limestone over the sea-bottom, and thus raise the rock to the level where reef-forming corals may grow, or within 100 to 150 feet of the surface; and that, in this way, coral reefs and islands *may* have been formed without subsidence. Mr. Guppy has shown that some coral-made limestone, in the southwest Pacific, actually has a base of limestone that had been made by other life than that of reef-corals. This is all the foundation for setting aside Darwin's conclusions. It is good ground for doubting, and a good reason for investigating the nature of the coral limestone in the various coral-reef regions of the Pacific at

* Volume xxx, pp. 89 and 169.

depths below the level of 100 to 150 feet—as I state in the article referred to, where I propose that deep borings should be made, under government authority, on a sufficient scale to settle the question. The borings have been made on Oahu; but, as I say above, the fossils of the reef-rock passed through below the coral-growing limit have not been examined and the subsidence therefore is not positively proved. There are many collateral arguments in favor of the Pacific coral-island subsidence reviewed in my paper which still remain strong; but they may be held in abeyance until the borings have been satisfactorily made. These and other points are discussed at length in the paper to which I have above referred.

I took no part in the controversy with reference to the statements of the dogmatic Duke of Argyll, knowing that the subject was in good hands. But I may here say that the charge which he made that no one had dared to bring forward and discuss the facts and views published by Mr. Murray and others against Darwin's theory was the more inexcusable that my paper had appeared as recently as in 1885 in the London Philosophical Magazine. The charge was based on ignorance of the facts on all sides, and on incapacity to appreciate the spirit actuating men of true science.

One other paper—on the question *whether volcanic action is a cause or not of trough-making over the Ocean's bottom, with a review of the ocean's depths illustrated by a new bathymetric chart*—will close this series with the exception of the promised paper on the rocks of the islands by E. S. Dana.

ART. XI.—*An Experiment bearing upon the Question of the Direction and Velocity of the Electric Current;** by EDWARD L. NICHOLS and WILLIAM S. FRANKLIN.

[Contributions from the Physical Laboratory of Cornell University, No. III.]

IN one of his recent articles in the *Annalen der Physik und Chemie*, Fœppl† has described an experiment in which the deflection of the galvanometer needle under the influence of a stationary coil of wire carrying an electric current, was compared with the deflection produced when the coil was given a high velocity of rotation; the axis of the coil being the axis of revolution. If the current traversing the coil had possessed direction and a finite velocity, a change in the de-

* Read before the American Association for the Advancement of Science; Cleveland meeting; August, 1888.

† A. Fœppl; Wiedemann's Annalen, Bd. 27, p. 410.

flection of the needle might have been looked for as the result of the revolution of the coil; the deflection being greater when the coil was revolving in the direction in which the current was flowing than when at rest, and less when the direction of the current was opposed to that of the coil. The result of the experiment was a negative one, the deflection of the needle being just the same when the coil was at rest as when it was in rapid rotation.

Fœppl's apparatus was inadequate to the end in view, for had the current consisted in a motion of translation of a single fluid, its velocity need not have greatly exceeded 300,000 centimeters per second to have rendered the difference between the deflections due to the stationary and to the rotating coil indistinguishable. The method is, however, capable of very much greater refinement than that attained in his experiment, and while modern views of the nature of the electric current are such as to lead us to look for a negative result, whatever the delicacy of the apparatus, the present condition of electrical theory is not such as to render a repetition of the experiment under improved conditions devoid of interest.

The present writers, by whom the details of a similar method had been developed before they became acquainted with Fœppl's work, have repeated his experiment with an apparatus capable of indicating the direction and velocity of the current, supposing it to have direction, even though that velocity were very large indeed.

A flat bobbin of hard rubber was carefully turned upon a lathe. It was $8{\cdot}25^{cm}$ in diameter and $1{\cdot}6^{cm}$ in thickness. The periphery was provided with a groove of rectangular cross-section. This groove was wound differentially with sixty-four turns of insulated copper wire. The winding was very compact and the wire was held in place within the groove by means of a brass tire or collar. Brass discs of slightly smaller diameter than the bobbin were screwed to the faces of the latter and well centered steel axles were inserted in these discs. Two brass supports, fastened to a hard rubber block which served as a base for the apparatus, carried bearings of Babbitt metal in which the steel axles of the bobbin rested. Each of the supports likewise bore two brushes of spring brass which could be so adjusted as to make contact with brass collars upon the axle of the coil. When the supports were connected with the terminals of a storage battery or other source of current, the circuit was completed through the coil; the current passing from one support to the axle upon that side by means of the bearing and brushes, thence to the brass disc upon the same side of the bobbin. From this disc, with which one terminal of the coil

made contact, the current traversed the windings and made exit through the opposite disc, axle and support.

The coil thus mounted was driven by a belt. It could be given a very high velocity of rotation and could be supplied with current equally well whether at rest or in motion. In some preliminary trials to determine the rate at which it could be driven with safety the source of power was a small high-speed water-motor. It was found that four hundred revolutions per second could be readily obtained and that such a velocity could be maintained without undue heating of the bearings. Upon one occasion a speed of nearly six hundred revolutions was reached, when the brass retaining band parted with a loud report and the bobbin was instantly stripped of every vestige of wire. The coil was then rewound and balanced anew, and the rate of four hundred revolutions per second, already determined as lying well within the limits of safety, was not exceeded during the remainder of the investigation.

The rate of revolution was readily and accurately determined from the pitch of the note emitted by the revolving coil, this determination being verified from time to time by two independent methods; namely from the siren-like note uttered by four screw-holes situated 90° apart upon one of the brass discs attached to the bobbin, and by estimating the velocity of the driving belt.

The needle, by means of which variations in the magnetic moment of the coil were to be detected, was placed immediately above the latter and as near to the windings as possible. It consisted of a steel wire, about 1^{cm} long and 1 millimeter in diameter, hardened and magnetized. It was suspended within a cylinder of copper and was rigidly connected with a precisely similar needle, by means of an aluminium support, the two needles being parallel, in the same vertical plane and about 5^{cm} apart, their poles in opposition. The aluminium support also carried a plane mirror and was suspended in the usual manner by a silken fibre. The astatic pair thus mounted was completely neutral and it was necessary to give it directive force by means of a governing magnet, the position of which was so selected as to give the system a fixed zero point and at the same time a very high degree of delicacy. Deflections were noted by use of a telescope and scale. The figure of merit of the apparatus was determined by substituting a coil of direct windings and known area, for the differentially wound coil, and reading the deflection due to ·00001 ampères of current.

Since, for the effect in question, the figure of merit was the same as though the revolving coil also were directly wound, it could then be derived from a comparison of the total areas of the two coils.

The most serious defect of this apparatus lay in the imperfect balancing of the differential windings. The position of the needle when a current traversed the coil always differed considerably from that which it assumed when the current was broken, and with one ampère of current the deflection amounted to several centimeters. The difficulty was however not of a nature to interfere altogether with the progress of the investigation and a series of readings were accordingly made with coil at rest and in motion. The rate of revolution during the determinations was 380 turns per second. The direction of the current through the coil and the direction of rotation of the latter were repeatedly reversed while the position of the needle was under observation. The result was an entirely negative one, no measurable effect upon the needle resulting from the motion of the coil. The current traversing the coil was measured upon a Moler's "swinging-arm" galvanometer. During a portion of the time it exceeded one ampère. A determination of the figure of merit of the apparatus made immediately after the conclusion of the series of observations gave as a result:

$$1^{mm} \text{ deflection} = 0{\cdot}0000164 \text{ ampères.}$$

When one ampère of current traversed the coil, therefore, a change in the apparent magnetic moment of the latter (due to rotation), in the ratio $1 : 1 \pm {\cdot}0000164$ would have shown itself in a change of deflection amounting to 1^{mm}. Such a variation could not have escaped notice.

The mean circumference of the windings of the coil was $23{\cdot}939^{cm}$, so that at 380 revolutions per second the wire had an average velocity, in the direction of its own length, of $9096{\cdot}82^{cm}$.

If we suppose the current to consist in the movement of electricity along the wire in a given direction, the velocity, relative to the conductor, being the same whether the coil is at rest or in motion, and the deflection of the needle to be due to the translatory movement of electricity with reference to the needle and proportional to that movement, it is easy to calculate the change in deflection, for any assumed current-velocity, which will be produced by a given rate of rotation of the coil.

Let V_w be the linear velocity of the conductor,
V_c the velocity of the current,
C_1 the current traversing the conductor,
C_2 the current necessary to produce a given deflection when traversing a directly wound coil of the same total area.

$$\text{Then } V_c = \frac{V_w C_1}{C_2},$$

In the case in question, a current-velocity of 554,680,000^{cm} per second would have been indicated by 1^{mm} change of deflection when the coil reached 380 revolutions per second. In these preliminary measurements, the highest degree of sensibility attainable by the method in question had been approached only in so far as the velocity of the revolving coil was concerned. It was evident that the number of ampère-turns in the revolving coil could be greatly increased without corresponding loss of speed, and that the question of further increasing the sensitiveness of the astatic pair, depended only upon our power to eliminate the disturbance due to the lack of complete balance in the differential windings of the coil.

To meet these ends a new coil was made for us by Mr. F. C. Fowler, the mechanician of the department of Physics, to whose skillful workmanship the excellent performance of the coils already described was due. This new coil was of the same diameter as the original one, and it was constructed in the same general manner. It was wound upon a box-wood spool, however, which was thick enough, axially, to admit of 390 turns of wire without changing the mean area of the windings. To avoid the very great difficulty of constructing a differentially wound coil so perfect that when carrying large currents, its effect upon the delicate astatic needle should be negligible, we resolved upon a modification in our method which should make the complete electrical balancing of the coil unnecessary. For the current from the storage battery used in our preliminary observations we substituted that generated by a small alternating-current dynamo giving 40,000 reversals a minute. The advantages of this change were very great, for there was no appreciable effect upon the needle, even when a much heavier current than we had attempted to use in our first experiment was traversing the coil. Under these conditions the sensitiveness of the astatic pair could be increased to the highest degree compatible with the maintenance of a permanent zero point, and the current traversing the coil was limited only by the heating of the wires.

The current from the alternating-current machine was measured by its heating effect upon a phosphor-bronze wire about fifty centimeters long, stretched vertically within a cylinder surrounded by a water-jacket. The elongation of the wire was made to move a small mirror by means of a simple device which need not be described here, and the angular movement of the mirror was read with a telescope and scale. This wire had been previously subjected to extended investigation and its reliability as an indicator of current was well established.* It

*See the Thesis of P. P. Barton and F. R. Jones: "The Measurement of Alternating Currents." MS. in the Library of Cornell University.

had been found that its indications when heated by an alternating current of the character used in our experiments agreed very closely indeed with those obtained by calibration with continuous currents of known intensity. Such a calibration was made in the present case, covering deflections from zero to 300 scale-divisions, which last-named reading corresponded to 5·00 ampères.

The new coil of 390 turns was now driven at 380 revolutions per second, the circuit being opened and closed and the current direction through the coil being repeatedly reversed, as in the former experiments. The amount of current traversing the coil was increased from time to time until the stretched wire indicated 4·26 ampères of alternating current, which was the largest quantity which it was deemed safe to permit the coils to carry, even for the few seconds necessary to the completion of an observation. The direction in which the coil revolved was likewise reversed from time to time. No change in the position of the needle due to the motion of the coil, nor to a reversal of the direction of the coil, nor to a reversal of the direction of the current within the coil could be detected, although the sensitiveness of the needle had been increased, about eight times, the current more than four times and the number of turns in the ratio of 390 to 64.

A re-determination of the figure of merit of the apparatus showed that 1^{mm} deflection now corresponded to ·00000043 ampères. An effect of much less than 1^{mm} due to the revolution of the coil, would have been clearly observable under the conditions of the experiment. The absence of such an effect seemed to warrant us in the conclusion, that if *direction* be ascribed to the electric current, its velocity must be such that the quantity of electricity conveyed past a given point in a unit of time, when the direction of the current was that in which the coil was travelling, did not differ from that transferred when the current and coil were moving in opposite directions by as much as one part in ten million—even when the linear velocity of the wire, as in our experiment was 9096·8 centimeters.

Now the velocity at which such a current must needs have traveled, in order that the revolution of the coil should increase or diminish the quantity of electricity passing the needle by an amount corresponding to a deflection of 1^{mm}, or in the case of the reversal of the direction of the current within the moving coil, corresponding to 2^{mm}, is found as before by multiplying the current in the coil by the linear velocity of the latter and dividing the product by the figure of merit of the apparatus.

We thus have

$$\frac{9096{\cdot}8\times 4{\cdot}26}{{\cdot}00000043} = 90{\cdot}1218\times 10^{9} \text{ centimeters.}$$

It is quite within safe limits to say therefore that we should have been able to detect a change of deflection due to the motion of the coil, even though the velocity of the current had been considerably in excess of one thousand million meters per second.

Physical Laboratory of Cornell University, August 1, 1888.

ART. XII.—*On the occurrence of Monazite as an accessory Element in Rocks;* by ORVILLE A. DERBY.

SOME five or six years ago Mr. John Gordon, an American mining engineer now engaged in commerce in Rio de Janeiro, brought to my attention a peculiar heavy yellow sand which had been sent to him from the province of Bahia under the supposition that it was tin sand. This on examination proved to be monazite with the composition, according to an analysis by Prof. Henri Gorceix of the Ouro Preto Mining School (*Comptes Rendus*, 1885): Phosphoric acid 28·7 per cent, oxide of cerium 31·3 per cent, oxides of didymium and lanthanum (?) 39·9 = 99·9. Inquiries instituted by Mr. Gordon and myself in regard to the locality and mode of occurrence of this sand revealed the fact that it occurs in considerable patches on the sea beach near the little town of Alcobaça in the southern part of the province of Bahia, where it seems to have been accumulated by natural concentration through wave action.

Attention having been thus drawn to this mineral, Prof. Gorceix has since detected yellow grains in the diamond sands of several localities of the provinces of Minas Geraes and Bahia which from giving the didymium lines in the hand spectroscope have been referred to monazite, and I have myself identified it by the same process in gold sands from several points in the provinces of Minas, Rio de Janeiro and São Paulo. The wide distribution of the mineral in the sea and river-sands of Brazil was thus established, but under circumstances that gave no clue to its origin.

Recently Mr Gordon informed me that in examining with a lens the sands of the beaches about Rio de Janeiro he found always yellow grains similar in appearance to the Bahia monazite and that on concentrating the sands in a copper miner's pan, he obtained a small quantity of white and yellow sand that

hung to the bottom of the pan behind the black iron minerals. Under the microscope the white grains show the characteristic form of zircon while the yellow ones, aside from their physical resemblance to the Bahia mineral, give like that, the didymium band in the hand spectroscope and the microchemical tests for phosphoric acid and cerium, so that their identity with monazite seems clearly established.

As gneiss is the only rock that is at all abundant about Rio de Janeiro, it was natural to suppose that the mineral so widely distributed in the sands might have come from that rock. About the same time Prince Pedro Augusto de Saxe Coburg Gotha discovered in an apatite-bearing streak of the gneiss of the Serra de Tijuca a minute yellow crystal with the physical aspect of monazite, but too small for chemical tests. This suggested the idea that, notwithstanding the small proportion of the mineral and the microscopic size of the grains, it was not altogether hopeless to look for it in the rock itself, while Mr. Gordon's method of concentration by panning was naturally suggested as the simplest and readiest mode of investigating the question. Under Mr. Gordon's instruction I soon acquired sufficient facility in the use of the pan to make a satisfactory concentration and with his aid some scores of tests have been made of the rocks in the vicinity of Rio and from about a dozen points in the provinces of Rio de Janeiro, Minas Geraes and São Paulo. Where decomposed rock was obtainable the tests were made on this by washing a quantity equal to a heaped double handful, care being taken to obtain material decomposed *in situ* and carefully freed from any extraneous wash. Where decomposed material was not at hand pieces of sound rock were ground in a mortar, a fragment the size of the fist or even smaller proving sufficient for a satisfactory test.

All the tests made on gneiss, granite and syenite have given, in addition to zircon, a greater or less quantity of microscopic crystals of a heavy yellow mineral apparently identical with the Bahia monazite. As no crystallographic study could be made, the identification has been based on the general appearance of the grains, their high specific gravity, and microchemical tests for phosphoric acid and cerium. In some few cases the yellow grains are lighter in color and duller in luster than the Bahia mineral, but as they give the phosphoric acid and cerium reactions they are presumed to represent a variety of monazite, or perhaps some other cerium-bearing phosphate. Their high specific gravity is proved by their behavior in the pan where they remain with the zircon, behind the other minerals, so that, after extracting the magnetite with a magnet, it is possible by careful manipulation to obtain these two min-

erals nearly free from titaniferous iron and garnet when these are present. The separation of the zircon is presumably favored by the minute size of the grains and by their prismatic form as it remains behind minerals as heavy or even heavier than itself when, as is generally the case, these are in larger grains. The yellow mineral, however, is frequently in as large grains as the titaniferous iron and of a similar rounded form and appears to hang back in virtue of its greater specific gravity. A few tests were made with fused chloride of lead (sp. gr. 5), which on cooling showed the yellow grains at the bottom of the ingot while the zircon and titaniferous iron were near the top. A number of the samples were tested with the hand spectroscope giving the didymium band, but owing to the difficulty of bringing together a sufficient number of such minute grains to give a perfectly satisfactory test, this means of identification was abandoned in favor of microchemical processes. All of the samples have been tested by treatment with sulphuric acid and molybdate of ammonia. In some cases crystals appeared in the sulphuric and oxalic acid solutions, along with those referred to cerium, which probably represent some other elements. It is possible that a more complete chemical and crystallogical study of the yellow grains of these residues may prove some of them to belong to minerals other than monazite, but in the impossibility of making such investigations here, they are all referred provisionally to that species. Samples of rock and residue from the granite of the Serra do Tijuca in the outskirts of Rio de Janeiro, in which the yellow grains are particularly abundant, have been placed in the hands of Prof. George H. Williams of Baltimore, in the hope that he may find them of sufficient interest to make such studies as, from the lack of appliances and the necessary training, are out of the question here.

The gneisses examined were obtained from a score or more points in and about the city of Rio, including porphyritic, granulitic and schistose varieties; from Kilometer 78 (ascent of the Serra do Mar), on the Dom Pedro II. railroad, and the station of Barra do Piraley on the same line; the station of Socego on the União Mineira railroad in the province of Minas Geraes; and the towns of Cutia, Piedade, Santos and Iguape in the province of São Paulo representing an extension of about 300 miles along the axis of the great gneiss region of the maritime group of mountains of Brazil. In every case zircon and the yellow mineral were found there, proving to be the most constant accessories since; of the ordinary accessory elements, garnet, rutile and the iron minerals, magnetite and ilmenite—the first two were frequently absent, while rarely only one of the iron minerals seemed to be pres-

ent. Rutile appears to be a comparatively rare element in these gneisses since the transparent red titaniferous grains referred to it were found only in two or three places in peculiar highly micaceous schistose layers, unusually rich in iron minerals. If, as is possible, these grains belong to some other mineral, then rutile is entirely lacking in the rocks examined. The gneiss from Socego and Cutia contains an abundance of sillimanite. All the gneisses examined belong to the class of biotite gneiss, except that from Santos which contains both muscovite and biotite and in this the yellow grains are rare in comparison with the zircon. No opportunity for examining a purely muscovite gneiss has yet been afforded. The relative proportions of zircon and the yellow mineral vary considerably in these tests, sometimes the one sometimes the other predominating. In the rock from Socego and from Kil. 78 D. Pedro II. railroad, the yellow mineral is particularly abundant.

A small number of granites have been examined with a similar result, that is to say, all of them give zircon with a heavy phosphate which in most cases appears to be identical with the Bahia monazite. The greater number of tests have been made on fine-grained biotite granites which give residues identical in appearance with those from the gneiss. The two specimens of muscovite granite examined from the station of Caieiras on the São Paulo railroad and from Sorocaba in the province of São Paulo gave a small quantity of lusterless whitish grains, quite different in appearance from those which we had become accustomed to refer to monazite, but on subjecting them to microchemical tests these also proved to be cerium-bearing phosphates. Yellow grains of the ordinary aspect are quite abundant in the small dykes of biotite granite in the gneiss about Rio and also in the larger masses of the Serra de Tijuca near Rio and at Pridade in the province of São Paulo, where Mr. Henry Bauer has kindly made a test for me. It is also abundant in uncommonly brilliant and perfect crystals in a small dyke in the gneiss of the Serra de Tingua, a peak of the Serra do Mar range near Rio. They are rare, in comparison with the zircon, in the large dykes near Campo Grande on the Santa Cruz branch of the Dom Pedro II. railroad, and near Bassa do Pirahy on the main line of the same roads, and in a small dyke at a place called Boa Vista on the Ribeira river in the Iguape region. It is interesting to note that the first two of these rocks carry cerium as a silicate in the form of orthite. The Tijuca granite is one of the richest rocks yet examined in the yellow mineral and a rough quantitative test was made on it as follows: A quantity of the rock disintegrated but not completely decomposed was dried in the sun and ground in a mortar to pass through a sieve

containing ·45 holes to the linear inch. As the decayed feldspar and mica, which may be presumed to carry the rarer and first formed minerals of this rock, went much finer than this, it was assumed that all of these were set free. From 1906 grams of the ground rock 0·557 grams or 0·029 per cent of residue consisting mainly of the yellow grains were obtained. As the small quantity of zircon and ilmenite in this residue is, probably, but little if any in excess of the loss in washing, the proportion of the yellow mineral can be safely put down as from 0·02–0·03 per cent of the entire mass of this rock.

A red syenite from the Serra do Stauba in the province of Bahia gave the yellow mineral in comparatively large grains, but these were few in number in comparison with the zircon. A mass of clay from the station of Sãn Joãs on the Sorocaba railroad in the province of São Paulo which is presumed to represent the syenitic rock of the vicinity, but which may be from gneiss, gave, with abundant zircons, a mineral giving the same reactions as those from the other rocks but lighter in color and duller in aspect than is usual.

The basic eruptives thus far examined, representing diabase, quartz-diorite mica-diorite and minette have afforded no trace of the yellow mineral.

It should be mentioned that in all these tests care has been taken to select samples representing the principal mass of the rock free from veins and mineral aggregates. In the course of these investigations grains which appear to represent several other rare minerals have been met with, but these have not yet been fully examined.

Since the above was written, a test has been made on a rock richer in monazite than any hitherto examined. This is a fine grained granitite exposed in a large dyke in the road from Engenho Noro to Jacarepagua in the outskirts of Rio de Janeiro. After thorough drying in the sun 3002 grams of the clay resulting from the decomposition of the rock was washed and the residue cleaned by the use of a heavy solution (sp. gr. 3·5), and of the electro-magnet. The residue weighing 2·24 grams, or 0·0746 per cent of the entire mass, consists principally of monazite in exceedingly fine grains with a small amount of zircon and a much smaller amount of other impurities that could not be completely separated without loss of material. The mixed monazite and zircon can safely be put down as 0·07 per cent of the rock.

In a recent excursion to the Argentine Republic Mr. Gordon obtained residues of zircon and monazite from the river-sands at Buenos Ayres and from gneiss and granite decomposed *in situ* at Cordoba.

Art. XIII.—*On the use of Steam in Spectrum Analysis;* by John Trowbridge and W. C. Sabine.

Among the difficulties with which the investigator in spectrum analysis must contend is that of obtaining a source of light which is free from constituents other than those which are under examination; and at the same time sufficiently powerful to enable him to photograph the spectra of the latter. The voltaic arc gives a sufficiently strong light to enable one to photograph throughout the visible spectrum; the electric carbons, however, are full of impurities, and it is difficult to interpret the spectra obtained by these means. Moreover, it is not easy to employ the arc spectrum for researches in the ultra violet portion of the spectrum. On the other hand the spark from a Ruhmkorff coil taken between terminals of metals, the spectrum of which we wish to examine, gives us in general spectra comparatively free from impurities, but its light is very feeble compared with that of the electric arc, and even when the spark is obtained by means of a powerful coil which is excited by an alternating dynamo machine an hour is necessary to obtain with a concave grating of 21 feet radius of curvature, on the most sensitive dry plate a photograph of the ultra violet spectra of copper at the wave length 2100.

It becomes an important question then to ascertain whether the time of exposure of the sensitive plate can be shortened by any process; for the outlay in obtaining one photograph in the ultra violet by the means hitherto at our command is very large, involving as we have said the running of an engine of at least two horse power for an hour. In our experiments with a jet of steam we find that the time of exposure of the sensitive plate can be shortened to at least one-third.

We were led to employ steam for the purpose of obtaining the spectra of oxygen and hydrogen with a more powerful electrical excitation than is possible in Geissler tubes. During the winter of 1886, when engaged upon the subject of oxygen in the sun, one of us in connection with Mr. C. C. Hutchins tried to obtain a powerful electric spark in an atmosphere of steam, but the experiments were unsatisfactory. The difficulties were chiefly in the way of proper insulation. Experiments showed that no containing vessel could be employed for the sides of the vessel conducting the electricty from one terminal of the Ruhmkorff coil to the other. No spark could be obtained, and the experiments were abandoned. During the present winter the experiments were renewed. The containing vessel was abandoned and the jet of steam was allowed to

impinge directly upon the spark. No effect could be perceived when there were no condensers in the secondary circuit, and with the introduction of small condensers the effect was not marked; but when the number of Leyden jar condensers was increased to four the effect of the jet of steam upon the electric spark was surprising. Its light immediately became comparable with that of the electric arc, enabling us to see the metallic spectra with the naked eye upon the ground glass of the photographic camera without the use of an eye piece. The chamber in which the spark and steam jet were placed became rosy red from the hydrogen arising from the dissociation of the steam. The hydrogen and oxygen lines in the air spectra became very much strengthened, a continuous spectrum showed itself in the neighborhood of the C line and also in the yellow, and a photograph of the air line and metallic line of the terminals employed could be taken in a third of the time which was necessary when the steam jet was not employed.

The apparatus consists merely of a tin box which is placed opposite the slit of the spectroscope. Steam enters at one side and is blown across the terminals of the Ruhmkorff coil which are placed in the box opposite the slit, an outlet on the side opposite from the place of entrance of the steam allows the waste steam to escape into the outer air.

The change of color of the spark is undoubtedly due to hydrogen. The light filling the box above referred to is decidedly red, and the hydrogen line C flashes out with great brilliancy in the midst of a continuous band of red in the spectrum. The metallic line from the terminals are greatly strengthened. The light from iron terminals is especially brilliant. Without the steam the spark between iron terminals seemed to consist of a single line of discharge. When the steam was turned on a great bundle of sparks appeared in the midst of a flaring light and the noise of the spark was greatly increased. This effect can undoubtedly be traced to increased conduction of the air space between the terminals of the Ruhmkorff coil.

The appearance of the spectra led us to examine the question of the spectrum of the Aurora Borealis and its connection with that of aqueous vapor. We believe that the theory that the shifting nature of the northern lights may be due to electrical discharges following strata of air more or less laden with aqueous vapor has been advocated. The appearance of the spectra of the electric spark in steam certainly leads one at first to favor this hypothesis. We have spoken of the marked brilliancy of the hydrogen line and of a continuous red band near this line. The continuous spectrum in the yellow is no less prominent. The observations which have been made on the northern lights do not enable one to make exact comparisons.

The lines given by different observers, however, do not appear to coincide with the prominent lines and bands observed in the air spectrum heightened by steam.

Other observers, among them Professors Liveing and Dewar, have employed steam to obtain steam lines, but we have been unable to find any reference to the remarkable economy in time and in waste of apparatus which results in the use of a jet of steam in spectrum analysis, when the spark method of obtaining the spectra of metals is employed.

Jefferson Physical Laboratory.

ART. XIV.—*A New Personal Equation Machine, for use with the Meridian-Circle;* by A. G. WINTERHALTER, Lieut., U. S. Navy.

DOCTOR WALTER F. WISLICENUS, in charge of the meridian-circle at the Strassburg Observatory, has lately given an account of his investigations, by means of an apparatus devised by himself, of his personal error in recording transit observations. The salient features of the machine are its attachment directly to the meridian-circle and the capability of using it in almost any position of the telescope. These warrant a brief exposition of the contents of Dr. Wislicenus's paper.*

The idea of determining the personal error in transit observations by means of an apparatus appears to have been first enunciated by Professor Kaiser in 1851 in the 5th volume of the Tijdsschrift voor de Wis- en Natuurkundige Wetenschappen. Prazmowski, in Warsaw, seems to have been the first to publish (in Cosmos, vol. iv, p. 445), in 1854, a scheme for a personal equation apparatus.

The author, after a more or less detailed study of the apparatus designed, successively, by Mitchel, Plantamour and Hirsch, C. Wolf, F. Kaiser, E. Kayser, Harkness, Hilgard and Suess, Eastman, R. Wolf, Bredichin, Christie, has arrived at the conclusion that in all previous instruments the disadvantage is presented of a horizontal position of the telescope used and, therefore, of an upright one of the observer, conditions not found in transit observations. From this and other considerations, the author lays down the following features to be complied with by such an apparatus:

1. The personal error should be determined with the same instrument with which observations are made.

* Untersuchungen über den absoluten persönlichen Fehler bei Durchgangsbeobachtungen. Von Dr. Walter F. Wislicenus, Privatdocent and Assistent an der Sternwarte zu Strassburg. Leipzig, 1888. Pp. 50, 9″x12″; one plate, with 3 figures. (Wilhelm Engelmann).

2. The apparatus should allow the error to be determined in various positions of the observer.

These two requisites are found in an apparatus arranged by Professor Bakhuyzen, but the second is secured by a disposition, which is not convenient and which requires much time for adjustment, i. e., for reflecting into the tube of the transit-circle telescope (placed at a determined elevation), the image of the artificial star by means of two mirrors, one of which is secured to the object-end of the telescope. Of the good points of the Leyden apparatus, as described by the author, I had the opportunity of satisfying myself on a recent visit to that observatory.

The task to be accomplished, according to the author, was the fulfillment of three conditions, viz:

1. The apparatus must be capable of application to a transit or meridian circle of the larger class.

2. It should not hinder the free movements of the telescope.

3. The artificial star should traverse the whole field and so imitate as faithfully as possible the motion of a true star.

The design of a machine of this character was facilitated by the fact that in the instrument used an artificial star was already present, namely, the small luminous image which is seen in telescopes with a central field-illumination, produced by the little mirror attached to the inner surface of the object glass. This method of illumining the field, now always used in the Repsold constructions, is, therefore, the first essential to the apparatus.

The machine designed was fitted to the Cauchoix transit of 132 millimeters aperture, an old instrument left by the French Faculty and later modernized for the Strassburg Observatory by the Repsolds. The apparent motion of the artificial star over the wires is secured by causing the ocular to slide laterally, when the image appears to move in the direction of motion of the ocular and is found in the center of its field. The machine's breaks are recorded as followed: On the ocular slide, insulated by a layer of caoutchouc, is a brass plate secured by two screws running into sockets of hard rubber. This bears, at right angles to the line of motion of the ocular, a steel spring having a small brass terminal, carrying a platinum-point, which touches another brass plate secured to the fixed ocular-head on top of an insulating layer. With an electric wire running to each of the insulated plates mentioned, the current is closed, when the platinum-point touches the brass underneath it. In the last-named brass plate a number of parallel lines, corresponding as accurately as possible to the position of the reticule-wires, have been drawn by a dividing engine and filled up with an insulating substance. The platinum-point in pass-

ing breaks the current successively for each artificial transit. It can be so set that the machine's break and the observer's break shall differ by a constant amount, allowing them to appear in succession on the chronograph sheet and be recorded by one pen.

The motor used was the clock-work of a Hipp chronograph. On one end of the horizontal axis of the telescope the two halves of a wheel are clamped. This wheel has a double row of teeth, one row gearing into the chronograph-train used as the motive power, the other into the connections for moving the ocular. At the latter, the arrangement contemplates, by means of the raising of a cam, the alternate engagement of a pinion in upper and lower racks for motions forward and backward. This change of direction can be made without the eye leaving the eye-piece. By combining wheels of different numbers of teeth, a large number of different speeds can be given to the clock-work.

I pass over a number of interesting experiments, such as those with a flat platinum-point for slow motions and a fine one for fast motions, experiments with various insulating substances for filling the grooves representing the wires, and will mention that the application of the apparatus to the Cauchoix instrument in question restricts the motion of the telescope through 116° of the 360° of a complete revolution, of which only about 26° are above the horizon. This facility of movement enables the observer to take up any desired position on or off the observing-couch. Designed for a new instrument, still more ample motion might be secured. The motive power should impart a regular motion and should be capable of regulation without the insertion of various wheels.

The author gives the results of numerous observations made for the determination of his personal error, using the equation

$$(1) \quad x = \frac{a+b}{2},$$

where x is the absolute personal error; a, the difference taken from the chronograph record between the machine's and the observer's breaks for motion in one direction; b, the same for motion in the opposite direction. All instrumental inaccuracies are eliminated, as may be seen from the two equations (a), (b), from which (1) is derived:

(a) $a = x + c \pm d + f$, for forward motion;
(b) $b = x - c \mp d - f$, for backward motion;

where, in seconds of time,

c is the error introduced by a slight eccentric displacement of the image produced by the motion of the ocular;

d, the time by which the machine's break occurs earlier or later than the transit;

f, the time by which the machine's break precedes the transit for all threads, by reason of the adjustment of the platinum-point;

$\pm$, prefixed according as the machine's break occurs $\frac{\text{earlier}}{\text{later}}$ than the corresponding transit of the artificial star.

The time elapsing between a transit and the corresponding automatic break must be the same for both directions of the motion of the ocular, which must be assured by the use of a uniformly acting clock-work. A table is computed to show the small influence of irregularities in the performance of the driving clock, provided only the ratio $\frac{t}{T}$ is confined within narrow limits; in this, t represents the amount in seconds by which the automatic break precedes or follows the actual transit; T, the time, in seconds, occupied in the forward motion of the ocular, $T \pm d$ being the time for backward motion.

The observations made by the author with this apparatus are exhaustive and may be divided into two principal groups: the first, consisting of three divisions, in each of which the rate of motion of the star remained unchanged, while the telescope was made to assume five typical positions; the second, in which the position of the telescope and rate of motion were uniformly changed, so that the artificial star should have that speed of transit corresponding to the observation of an actual star in transit in that position of the telescope.

In observing, the artificial star was allowed to run over the whole field and the transits over 21 threads were noted, giving 21 values for the personal error, each depending on two transits, for forward and backward motions of the ocular. The means which I have collated below are formed from those of several series on a number (usually five) of days. The author uses in his notation the expression,

Actual transit − observed = personal equation.

So that the result is the correction and has the sign with which it is to be applied to an observation.

First Group.

1.	2.	3.	4.
+90°	−0ˢ·190	−0ˢ·013	+0ˢ·519
+45	−0 ·178	−0 ·020	+0 ·477
0	−0 ·207	−0 ·046	+0 ·323
−45	−0 ·127	+0 ·041	+0 ·410
−90	+0 ·140	+0 ·497	+1 ·772

In this table, the first column indicates the position of the telescope, counting from the horizon, + above it, − below;

the remaining columns give the personal equation with rates of motion of the star corresponding, respectively, to 11° 21′·0, 60° 8′·5 and 80° 19′·0 declination.

The general deduction is: In the author's personal equation a dependence is proved on the position of the telescope, i. e., on the corresponding position of the body.

Second Group.

1.		2.
−15°	45′	−0ˢ·115
+15	0	−0 ·096
+59	40 U. C.	+0 ·017
+82	40 L. C.	+0 ·463
+59	40 L. C.	+0 ·040

In this table, the first column gives the setting in declination as read off on the circle, with an indication of upper and lower culminations, the motion being, as stated, that of a star of that declination; the second column, the personal equation.

The general deduction is: the amount of the personal equation is algebraically increased and changes sign (becoming positive) for slow motions; this is also shown by the first group. Besides, the second group indicates, although not as plainly as the first, the dependence of the equation on the position of the observer.

The author finds also that in time his equation changes. For a star of equatorial motion, it was found

1886. Dec. 13–22:	−0ˢ·178;
1887. May 23–27:	−0 ·105;
1888. March 17:	+0 ·148.

A comparison of the two groups with results obtained in Leyden in 1886 is interesting, but does not safely show a variation depending on varying positions of the telescope.

Physiological investigations were not attempted nor were generalizations for others, but the author draws two conclusions applicable to his own case.

The absolute personal error is with stars of a mean speed of transit a minimum, increases with an increase and decrease of the speed and, in the latter case, in general more rapidly than in the former.

The absolute personal error is, in general, dependent on the position of the telescope and the requisite position of the body of the observer, as also on the observed object,—star or limb.

An ingenious disposition of the apparatus permitted the author to examine his personal error in observing the limb of disks of various diameters. A brass ring was blackened and

fastened to the cell of the eye-piece on the side nearest the reticule, leaving, however, the entire aperture free. On this ring a glass-plate, 0·1 millimeter thick, was secured with shellac. This plate had a circular opening in its center and was attached in such a position that the edge of the opening passed through the center of the ring. It is obvious that the illumination of the field was now divided into a bright and a somewhat darker part by an arc passing through the center of the field.

There is seen, then, a part of a bright disk on a half-bright ground, transiting the wires by the motion of the ocular, as before. By using plates of different-sized openings, disks were obtained corresponding to angular radii of

$$16'\ 2'',\ 11'\ 27'',\ 7'\ 27'',\ 1'\ 5'',\ 10''.$$

The motion in one direction gives the transit of either the preceding or the following limb; to get the same limb for the reversed motion, it would be necessary to turn the ocular through 180°. Owing to a limited time, the observations were made only so as to take the mean between errors of preceding and following limbs.

For a motion corresponding to that of a star of 11° 21′ declination, the personal equations in observing the limbs, in the order of angular radius above given, were:

$$+0^s{\cdot}089,\ +0^s{\cdot}259,\ +0^s{\cdot}213,\ +0^s{\cdot}183,\ +0^s{\cdot}157,$$

while for a star the equation in the same position of the telescope was found to be $+0^s{\cdot}148$. Forming the differences limb − star, in the same order, we have:

$$-0^s{\cdot}059,\ +0^s{\cdot}111,\ +0^s{\cdot}065,\ +0^s{\cdot}035,\ +0^s{\cdot}009.$$

The observations in this last investigation are not complete, but it seems to be established that the author's personal equation is different for observation of limb and of star, the difference generally increasing with the increase of the size of the disk observed.

The advantage of the author's apparatus remains in the fact that with it the circumstances of transit observations can be closely imitated, both as regards the position of the observer and the fulfillment of other desirable conditions. Objections of complication can scarcely be made, as it is not likely that an apparatus of an entirely simple character will be devised to permit a complete investigation of the peculiarities of the personal error.

Art. XV. — *The Subsidence of Fine Solid Particles in Liquids;** by Carl Barus.

1. Throughout this paper the motion of the corpuscles through the liquid is of the kind premised in treating capillary transpiration: in both cases solid and liquid move relatively to each other under conditions by which eddies are excluded, and the whole kinetic energy is at once converted into molecular kinetic energy, or heat.

In my earlier work I endeavored to analyze the phenomenon of sedimentation into parts such that the conditions under which the subsidence is to be explained from a chemical, or from a physical, point of view, may be better discernible. To do this I first considered the question in its purely mechanical aspects.† If P be the resistance encountered by a solid spherule of radius r, moving through a viscous liquid at the rate x, and if k be the frictional coefficient, then $P=6\pi krx$. Again, the effective part of the weight of the particle is $P'=\frac{4}{3}\pi r^3(\rho-\rho')g$, where g is the acceleration of gravity and ρ and ρ' the density of solid particle and liquid, respectively. In case of uniform motion $P=P'$. Hence $$x=\frac{2}{9k}r^2(\rho-\rho')g \quad \ldots\ldots\ldots (1)$$

In any given case of thoroughly triturated material the particles vary in size from a very small to a relatively large value; but by far the greater number approach a certain mean figure and dimension. An example of this condition of things may be formulated. To avoid mathematical entanglement I will select $$y=Ax^{\frac{3}{2}}e^{-x^2} \quad \ldots\ldots (2)$$ where y is the probable occurrence of the rate of subsidence x. If now the turbidity of the liquid (avoiding optical considerations) be defined as proportional to the mass of solid material particles suspended in unit of volume of liquid, then the degree of turbity which the given

* The present article, being a continuation of Bulletin U. S. G. S., No. 36, 1886, is largely based the experimental evidence there tabulated. Mr. William Durham (Chem. News, xxx, p. 57, 1874; id. xxxvii, p. 47, 1878) was the first to give an incentive to this class of experiments. Much of our knowledge of the effect of precipitants is due to him. Moreover, the theoretical views at which he ultimately arrives may be regarded as a definite point of departure. In this country Prof. T. S. Hunt (Proc. Boston Soc. Nat. Hist., Feb., 1874), Prof. W. H. Brewer (National Acad. Sc., 1883; Am. Journal, (3), xxix, p. 1, 1885) and Prof. C. R. Stuntz (Cincinnati Soc. Nat. Hist., Feb., 1886) have occupied themselves with similar work. Prof. Stuntz's paper contains further references among others to Waldie's results (Journal Asiatic Soc., of Bengal, 1873; Chem. News, 1873). Meanwhile Mr. W. Hallock has made experiments on the subsidence of lampblack in connection with his work on the density of that substance (Cf. Bull. U. S. G. S., No. 42, p. 132, 1887). I may add that my own experiments were suggested by Prof. Brewer's memoir.

† Cf. G. Kirchhoff, Mathematische Physik, lecture 26, § 4, 1876.

ydx particles add to the liquid is, *caet. par.*, proportional to r^3ydx, where r is the mean radius. Hence the turbidity, T, at the outset of the experiment (immediately after shaking) is $T=T_0\int_0^\infty r^3ydx=T_0$, where equations (1) and (2) have been incorporated.

If the plane at a depth d below the surface of the liquid be regarded, then at a time t after shaking the residual turbidity is

$$(3)\ \ldots\ldots\ T_d=T_0\int_0^{\frac{d}{t}} r^3ydx=T_0\left(1-\left(1+\frac{d^2}{t^2}\right)e^{-\frac{d^2}{t^2}}\right).$$

The equation describes the observed occurrences fairly well. In proportion as the time of subsidence is greater, the tube shows opacity at the bottom, shading off gradually upward, through translucency, into clearness at the top. If instead of equation (2) there be introduced the condition of a more abrupt maximum, if in other words the particles be very nearly of the same size, then subsidence must take place in unbroken column capped by a plane surface which at the time zero coincided with the free surface of the liquid. Again suppose one-half of the particles of this column differ in some way uniformly from the other half. Then at the outset there are two continuous columns coinciding, or as it were interpenetrating throughout their extent. But the rate of subsidence of these two columns is necessarily different, since the particles, each for each, differ in density, radius and frictional qualities by given fixed amounts. Hence the two surfaces of demarcation which at the time zero coincided with the free surface. In general if there be n groups of particles uniformly distributed, then at the time zero n continuous columns interpenetrate and coincide throughout their extent. At the time t, the free surface will be represented by n consecutive surfaces of demarcation below it, each of which caps a column, the particles of which form a distinct group. This phenomenon is Prof. Brewer's stratified subsidence. In the case of particles which have undergone an earlier fractionated sedimentation either in nature or in the arts, the occurrence of groups possessing the distinctive characteristics here discussed is not improbable. On the other hand when during subsidence the surfaces of demarcation follow each other in regular succession, one is tempted to look for something more than an adventitious cause for the phenomenon. An orderly arrangement of groups of particles might for instance indicate successive stages of hydration. Cf. § 6. In case of stratified subsidence, it is convenient to speak of the planes of demarcation as orders of surfaces, numbering them from the top downward. Seven or even ten orders are not uncommon.

2. With these deductions as a point of departure, I then attempted to find relations between rates of subsidence, the viscous and capillary properties of the liquid, and its electrical behavior, under analogous conditions of concentration and of temperature. This general survey proved that the phenomenon of sedimentation is unique; that the frictional resistances encountered by the particles are apparently different from the viscosities of the liquids in which subsidence takes place; that many of the occurrences observed are closely allied to the electrolytic and the capillary properties of this liquid. Finally utilizing Prof. Brewer's stratified subsidence, which I obtained very clearly with certain kinds of tripoli, I commenced a series of more rigorously quantitative measurements showing that *caet. par.*, rate of subsidence is primarily dependent on the turbidity of the mixture.

In my experiments with tripoli, the observed rates of subsidence (cm/(sec$\times 10^6$)) in ether, alcohol, water, glycerine were 7500, 1300, 3, 0·09, respectively; but owing to the difference in character of the divers precipitates, these figures have no further signification than to emphasize the said difference in character. §§ 5,6. Let water and ether be mixed so that there shall be equal bulks of etherized water below, and aqueous ether above, and then let the dust (bole) be added. If now the mixture is violently shaken and then allowed to subside, the ether is washed clean of particles in a few minutes whereas the sediments remain suspended in water for weeks and even months. Here however the separation and subsidence is promoted by the surface energy of water.

On the other hand if dry tripoli be added to ether dried over $CaCl_2$, in a test tube, and if the tube be held obliquely after shaking, subsidence is so rapid that the upward current of ether along the upper line of the tube is almost tempestuous.

The close relation of the present phenomena to electrolytic phenomena appears at once by observing that so little as a single molecule of HCl (for instance) added to 10,000 or even 50,000 molecules of H_2O, produces appreciable increase of the rate of subsidence. Remembering that the arrangement is in three dimensions, and supposing the molecule HCl as large as the molecule H_2O, the effect of the molecule HCl must be appreciable at a distance of at least 30 times its own radius,* and extend much beyond this asymptotically. Quincke's radius

* The estimated diameter of H_2O (distance between centers of adjacent molecules $2\rho = 40/10^{9cm}$) I take from Kohlrausch (Wied. Ann., vi, p. 209, 1879). In how far the molecule of liquid water differs from H_2O remains to be seen. Indeed the underlying cause of continuous and of discontinuous fusion and vaporization, and the cause of allied phenomena such as retarded solidification, ebullition, etc., seems clearly to be some form of polymerization. Nevertheless the atomic theory in its present stage of development fails to suggest a satisfactory mechanism for these occurrences.

of capillary attraction, ·000005^{cm}, being at least 100 times the molecular radius H_2O, it appears that the striking effect of the molecule HCl in accelerating subsidence, is not an abnormal occurrence, at least from a physical point of view. Other relations are adduced in the Bulletin.

3. To account for these phenomena as a whole, Mr. Durham, in his second paper, proposes an hypothesis in virtue of which the scope of the action of affinity is enlarged, and suspension regarded as the lower limit of solution. This view is rapidly gaining ground; nevertheless without concise experimental reference to the density and size of the solid particles and the viscosity of the liquid, Mr. Durham's explanation contains no sufficient reason for the observed suspension, nor for changes of rate of subsidence. Prof. Brewer's ingenious hypothesis of colloidal hydrates so constituted that the particles may ultimately swell up and float something like gelatinous silica, or even like starch grains, is more direct; and before further reasons of the cause of suspension are sought the validity of this inference must be tested. This test is feasible, I think. If the phenomenal difference of rate with which the same particles subside in water and in ether is due to volume changes of the particles, then a marked difference in the density of the sediment (clay or tripoli) in water and in ether respectively, must be experimentally demonstrable. Cf. equation (1). I made these experiments with both solids, using two nearly identical density flasks, one for water and the other for ether, in the usual way. The powders were sampled and dried at 200° in an air bath for half a day, transferred to the pycnometers, dried and weighed when cold. They were then left in a dessicator for 18 hours and again weighed; and finally dried in vacuo and weighed. The results throughout were satisfactorily constant. By aid of an apparatus specially devised for the purpose, the two flasks were once more thoroughly exhausted (mercury air pump), and then filled with water and with ether respectively, in vacuo, over sulphuric acid. In both cases (the experiments were made consecutively), the vacuum ebullition was kept up for some time to give full assurance of the expulsion of air, etc. The density of the ether had been previously determined by the same flasks, once for each experiment.

Thus I obtained for tripoli,

$$\left\{\begin{array}{l}\text{In water, density} = \Delta_w = 2{\cdot}672,\\ \text{In ether, density} = \Delta_e = 2{\cdot}697.\end{array}\right.$$

Again, I obtained for white bole,

$$\left\{\begin{array}{l}\text{In water, } \Delta^w = 2{\cdot}639,\\ \text{In ether, } \Delta^e = 2{\cdot}663.\end{array}\right.$$

The manipulation being somewhat difficult, the observed

differences of Δ_w and Δ_e are no larger than the many sources of error led me to anticipate, particularly in view of the fact that the two samples for ether and for water may not have been absolutely identical. The concentrated ether used was the same commercial reagent with which I obtained the subsidence phenomena. In consequence of the high but normal values of both Δ_w and Δ_e, I saw no need of specially purifying it. I add finally that after calcination, the dry tripoli lost 1·2 per cent in weight, and the dry bole about 11·4 per cent. In both cases this is probably water of constitution, the elimination of which was of course not permissible. In spite of differences of chemical composition, the bole and tripoli particles are about equally suspended before and after calcination, and the phenomena with ether dried over $CaCl_2$ are identical with the above.

4. These results show that the densities in the two cases (sediment in water and in ether respectively), are not essentially different. Moreover, the density of tripoli is so nearly that of quartz, and the density of bole so nearly that of kaolinite, as to leave the hydration hypothesis very seriously in the lurch, so far as favorable evidence is concerned. It is improbable that the addition of water to the dry powder is accompanied by sufficiently marked volume changes; it is certain that the enormous variation of rates of subsidence actually observed when the particles descend in water, in solutions, and in ether, must be referred to some general cause apart from the density of the particles and the viscosity of the liquids.

5. This premised, the explanation of sedimentation may be so made as to give emphasis to the following principle: If particles of comminuted solid are shaken up in a liquid, the distribution of parts after shaking will tend to take place in such a way that the potential energy of the system of solid particles and liquid, at every stage of subsidence, is the minimum compatible with the given conditions. In the case of solid particles and pure water the configuration answering this condition, is schematically,

Particle, water. . . . . Particle, water.

In the case of solid particles and ether, or of solid particles and solutions, this configuration is schematically,

Particle, particles. . . . . ether, ether.

For the exemplification of this inference my paper contains varied experimental evidence. The principle asserts that in case of water the sediment is graded and the suspended material granular, whereas in ether the sediment is apparently homogeneous, as I found; that the bulk of sediment is necessa-

rily less in water than in ether, being compact in the first instance and of a microscopically arched or castellated internal structure in the second instance, as I found; that the effect of a precipitant is particularly marked when the mixture is densely turbid with relatively coarse particles, as I found; that finally the phenomena of sedimentation must be of a distinct and special kind, and by no means the immediate converse of capillary viscous transpiration. The inferences are thus based on equation (1) above, and follow at once when k and ρ are nearly constant. In the Bulletin, I computed the relative size (radii) of particle of tripoli subsiding in water, alcohol, ether, to be 1, 19 and 24 respectively.*

It is exceedingly curious to note in case of water, that despite the phenomenally large surface energy of the liquid, subsidence takes place in such a way that for a given mass of suspended sediment, the surfaces of separation are a maximum. On the other hand, in case of subsidence in ether, or in salt solutions, the solid particles behave much like the capillary spherules of a heavy liquid, shaken up in a lighter liquid with which it does not mix. In other words the tendency here is to reduce surfaces of separation to the least possible value, large particles growing in mass and bulk mechanically at the expense of smaller particles. Finally it is clear that the condition of stratified sedimentation is very slow subsidence of a granular precipitate.

The experimental evidence adduced bears directly on the size of the particles of any precipitate. A given mass of small solid particles presupposed, the observations of the foregoing paragraph make it probable that the potential energy of the system of solid particles and liquid increases with the radius of the particle. These observations also show that the potential energy of the system of solid particles alone, decreases as the size of the particles increases, a state of things due both to the immediate action between solid particles, and probably also to the surface energy of the liquid in which suspension takes

* This is the first of the hypotheses which I develop in detail in Bulletin No. 36, pp. 34, 35, 37. In a re-calculation since made with more accurate values of k (water 0^0 to 100°, Slotte in Wied. Ann., xx, p. 262. 1883; ethyl and methyl alcohol, Graham in Phil. Mag., (4), xxiv, p. 238, 1861; ether, Landolt and Boernstein's Tables, p. 153; glycerine estimated $\eta = 10$ g cm^{-1} sec.$^{-1}$), the radii of the particles in water, ethyl alcohol, methyl alcohol, ether and glycerine are found to be $r = 0{\cdot}000009^{cm}$, $0{\cdot}00019^{cm}$, $0{\cdot}00018^{cm}$, $0{\cdot}00020^{cm}$ and $0{\cdot}00005^{cm}$ respectively. In case of bole suspended in water at 15° and 100°, the radii were approximately $< 0{\cdot}000010^{cm}$ and $> 0{\cdot}000020^{cm}$. § 6 points out, that whereas these dimensions may be called in question when considered absolutely, the relative values of r are probably true.

The fact that particles so extremely light descend at all is a result showing the almost marvelous delicacy of these experiments. In case of tripoli-water, for instance, the estimated weight of particle is only $1/10^{11}$ milligrams; being invisible microscopically it must have weighed less than $1/10^{10}$ milligram.

place. Under these conflicting conditions it is probable that there is a critical shell, within which the energy solid-liquid decreases less rapidly than the energy solid-solid; and beyond which shell the energy solid-liquid increases more rapidly than the energy solid-solid. This critical shell, being compatible with the conditions of minimum potential energy of the subsiding system as a whole, is the size of the precipitated particles: for any change of the radius of a particle bounded by the critical shell, implies an expenditure of work, which under the usual conditions of precipitation is not available.

6. I have finally to endeavor to assign some value to the radius of the critical shell for the case of the above water suspensions. In my experiments with tripoli, rates of subsidence, x, in *cm* (*sec.* $\times 10^6$), varied from $x = 1$ to $x = 20$, according as higher orders of surfaces or turbidities of lower degree, were chosen. Taking the more usual value, $x = 3$, the radius of the particles subsiding was probably not less than 400 times the molecular radius of water. The bole particles under analogous conditions of suspension in H_2O, were smaller, probably only 100 water radii. In Prof. Brewer's indefinitely suspended clays the limit of comminution can not be estimated at all, except perhaps from purely optical considerations.* Whether in this extreme case colloidal hydration with concomitant volume changes is still demonstrably absent, remains to be seen. To test it, a sufficient quantity of the extremely fine material would have to be collected and dried by low temperature evaporation.

Again in Bulletin No. 35 (p. 21), I point out at some length that "when the particles decrease (in size) from some estimable mean value indefinitely," liquid viscosity, being at least partially if not largely kinetic in character, can no longer be considered constant as regards time; that therefore a particle may descend, or in other words the continuous and constant action of gravity produce an effect even when the weight of the particle is below the mean or physically measurable value of the friction encountered; that the limits of time-variation of viscosity will increase as the radius of the circumscribed space decreases. In such a case the particle to be stationary must weigh less than the lower limit of the variable viscosity—a quantity which may be reasonably conceived to approach zero very nearly. I carried these inferences one step further by supposing, rationally, I think,

* The optical properties of light reflected from particles small in comparison with the wave length of light are discussed by Stokes (Phil. Trans., 1852, p. 530). How large a particle may be without interfering with optical clearness, I can not say. It is well to bear in mind that the suspension of corpuscles consisting of a small number, say ten molecules per critical shell, would bear the outward characteristics of solution.

that the limits within which this *elementary* viscosity (say) varies, will increase with the degree of molecular agitation of the liquid. On the basis of this postulate I then endeavored to explain sedimentation kinetically, both in its relations to temperature and the effect of precipitants.

One point which antagonizes this hypothesis must not be lost sight of: Two or more particles sufficiently near together will tend to screen each other; and receiving impact mainly on their outer surfaces will be brought to permanent coherence so long as the conditions of pronounced molecular agitation last. This is actually observed in water suspensions at 100°, in solution-suspensions, in ether suspensions, etc. In these instances there seems to be difficulty in preserving the granular state (Bull. 36, p. 38).

To pass judgment on the validity of such explanation, it is necessary to have in hand better statistics of the size of the particles relatively to the water molecule, than are now available. Inasmuch as the particles in pure water are individualized and granular, it is apparantly at once permissible to infer the size of the particles from the observed rates of subsidence. But my observations show that the said rate decreases in marked degree with the turbidity of the mixture. Hence the known formulæ for single particles are not rigorously applicable, though it cannot be asserted whether the cause of discrepancy is physical or mathematical in kind. It follows that special deductions must be made for the subsidence of stated groups of particles before an estimate of their mean size can fairly be obtained.

Phys. Lab., U. S. G. S., Washington, D. C.

ART. XVI.—*A Comparison of the Electric Theory of Light and Sir William Thomson's Theory of a Quasi-labile Ether;* by J. WILLARD GIBBS.

A REMARKABLE paper by Sir William Thomson, in the November number of the *Philosophical Magazine*, has opened a new vista in the possibilities of the theory of an elastic ether. Since the general theory of elasticity gives three waves characterized by different directions of displacement for a single wave-plane, while the phenomena of optics show but two, the first point in accomodating any theory to observation, is to get rid (absolutely or sensibly) of the third wave. For this end, it has been common to make the ether incompressible, or, as it is sometimes expressed, to make the velocity of the third wave infinite. The velocity of the wave of compression becomes in fact infinite as the compressibility vanishes. Of

course it has not escaped the notice of physicists that we may also get rid of the third wave by making its velocity zero, as may be done by giving certain values to the constants which express the elastic properties of the medium, but such values have appeared impossible, as involving an unstable state of the medium. The condition of incompressibility, absolute or approximate, has therefore appeared necessary.* This question of instability has now, however, been subjected to a more searching examination, with the result that the instability does not really exist "*provided we either suppose the medium to extend all through boundless space, or give it a fixed containing vessel as its boundary.*" This renders possible a very simple theory of light, which has been shown to give Fresnel's laws for the intensities of reflected and refracted light and for double-refraction, so far as concerns the phenomena which can be directly observed. The displacement in an aeolotropic medium is in the same plane passing through the wave-normal as was supposed by Fresnel, but its position in that plane is different, being perpendicular to the ray instead of to the wave-normal.†

It is the object of this paper to compare this new theory with the electric theory of light. In the limiting cases, that is, when we regard the velocity of the missing wave in the elastic theory as zero, and in the electric theory as infinite, we shall find a remarkable correspondence between the two theories, the motions of monochromatic light within isotropic or aeolotropic media of any degree of transparency or opacity, and at the boundary between two such media, being represented by equations absolutely identical, except that the symbols which denote displacement in one theory denote force in the other, and *vice versâ*.‡ In order to exhibit this correspondence completely and clearly, it is necessary that the fundamental principles of the two theories should be treated with the same generality, and, so far as possible, by the same method. The immediate consequences of the new theory will therefore be deduced with the same generality and essentially by the same method which has been used with reference to the electric theory in a former volume of this Journal (vol. xxv, p. 107).

* It was under this impression that the paper entitled "A Comparison of the Elastic and the Electric Theories of Light with respect to the Law of Double refraction and the dispersion of colors," in the June number of this Journal, was written. The conclusions of that paper, except so far as respects the dispersion of colors, will not apply to the new theory.

† Sir William Thomson, *loc. citat.* R. T. Glazebrook, *Phil. Mag.*, December, 1888.

‡ In giving us a new interpretation of the equations of the electric theory, the author of the new theory has in fact enriched the mathematical theory of physics with something which may be compared to the celebrated *principle of duality* in geometry.

The elastic properties of the ether, according to the new theory, *in its limiting case*, may be very simply expressed by means of a vector operator, for which we shall use Maxwell's designation. The *curl* of a vector is defined to be another vector so derived from the first that if u, v, w be the rectangular components of the first, and u', v', w', those of its curl,

$$u' = \frac{dw}{dy} - \frac{dv}{dz}, \quad v' = \frac{du}{dz} - \frac{dw}{dx}, \quad w' = \frac{dv}{dx} - \frac{du}{dy}, \tag{1}$$

where x, y, z are rectangular coördinates. With this understanding, if the displacement of the ether is represented by the vector $\mathfrak{E}$, the force exerted upon any element by the surrounding ether will be

$$- \mathrm{B}\ \mathrm{curl}\ \mathrm{curl}\ \mathfrak{E}\ dx\ dy\ dz, \tag{2}$$

where B is a scalar (the so-called *rigidity* of the ether) having the same constant value throughout all space, whether ponderable matter is present or not.

Where there is no ponderable matter, this force must be equated to the reaction of the inertia of the ether. This gives, with omission of the common factor $dx\ dy\ dz$,

$$\mathrm{A}\ddot{\mathfrak{E}} = - \mathrm{B}\ \mathrm{curl}\ \mathrm{curl}\ \mathfrak{E}, \tag{3}$$

where A denotes the density of the ether.

The presence of ponderable matter disturbs the motions of the ether, and renders them too complicated for us to follow in detail. Nor is this necessary, for the quantities which occur in the equations of optics represent average values, taken over spaces large enough to smooth out the irregularities due to the ponderable particles, although very small as measured by a wave-length.* Now the general principles of harmonic motion† show that to maintain in any element of volume the motion represented by

$$\mathfrak{E} = \mathfrak{A} e^{2\pi\iota\frac{t}{p}}, \tag{4}$$

$\mathfrak{A}$ being a complex vector constant, will require a force from outside represented by a complex linear vector function of $\mathfrak{E}$, that is, the three components of the force will be complex

* This is in no respect different from what is always tacitly understood in the theory of sound, where the displacements, velocities, densities considered are always such average values. But in the theory of light, it is desirable to have the fact clearly in mind on account of the two interpenetrating media (imponderable and ponderable), the laws of light not being in all respects the same as they would be for a single homogeneous medium.

† See Lord Rayleigh's *Theory of Sound*, vol i, chapters iv, v.

linear functions of the three components of $\mathfrak{E}$. We shall represent this force by

$$\mathrm{B}\,\Psi\ddot{\mathfrak{E}}\,dx\,dy\,dz, \tag{5}$$

where Ψ represents a complex linear vector function.*

If we now equate the force required to maintain the motion in any element to that exerted upon the element by the surrounding ether, we have the equation

$$\Psi\ddot{\mathfrak{E}} = -\operatorname{curl}\operatorname{curl}\mathfrak{E}, \tag{6}$$

which expresses the general law for the motion of monochromatic light within any sensibly homogeneous medium, and may be regarded as implicitly including the conditions relating to the boundary of two such media, which are necessary for determining the intensities of reflected and refracted light.

For let $u,\ v,\ w$ be the components of $\mathfrak{E}$,
$u',\ v',\ w'$ " " curl $\mathfrak{E}$,
$u'',\ v'',\ w''$ " " curl curl $\mathfrak{E}$,

so that

$$u' = \frac{dw}{dy} - \frac{dv}{dz}, \quad v' = \frac{du}{dz} - \frac{dw}{dx}, \quad w' = \frac{dv}{dx} - \frac{du}{dy},$$
$$u'' = \frac{dw'}{dy} - \frac{dv'}{dz}, \quad v'' = \frac{du'}{dz} - \frac{dw'}{dx}, \quad w'' = \frac{dv'}{dx} - \frac{du'}{dy};$$

and let the interface be perpendicular to the axis of Z. It is evident that if u' or v' is discontinuous at the interface, the value of u'' or v'' becomes in a sense infinite, *i. e.*, curl curl $\mathfrak{E}$, and therefore by (6) $\Psi\ddot{\mathfrak{E}}$, will be infinite. Now both $\mathfrak{E}$ and Ψ are discontinuous at the interface, but infinite values for $\Psi\ddot{\mathfrak{E}}$ are not admissible. Therefore u' and v' are continuous. Again, if u or v is discontinuous, u' or v' will become infinite, and therefore u'' or v''. Therefore u and v are continuous. These conditions may be expressed in the most general manner by saying that the components of $\mathfrak{E}$ and curl $\mathfrak{E}$ parallel to the interface are continuous. This gives four complex scalar conditions, or in all eight scalar conditions, for the motion at the interface, which are sufficient to determine the amplitude and

* It amounts essentially to the same thing, whether we regard the force as a linear vector function of $\mathfrak{E}$ or of $\ddot{\mathfrak{E}}$, since these differ only by the constant factor $-\frac{4\pi^2}{p^2}$. But there are some advantages in expressing the force as a function of $\ddot{\mathfrak{E}}$, because the greater part of the force, in the most important cases, is required to overcome the inertia of the ether, and is thus more immediately connected with $\ddot{\mathfrak{E}}$.

phase of the two reflected and the two refracted rays in the most general case. It is easy, however, to deduce from these four complex conditions, two others, which are interesting and sometimes convenient. It is evident from the definitions of w' and w'' that if u, v, u', and v' are continuous at the interface w' and w'' will also be continuous. Now $-w''$ is equal to the component of $\Psi\ddot{\mathfrak{E}}$ normal to the interface. The following quantities are therefore continuous at the interface:

$$\left.\begin{array}{l}\text{the components parallel to the interface of } \mathfrak{E},\\ \text{the component normal to the interface of } \Psi\mathfrak{E},\\ \text{all components of } \operatorname{curl}\mathfrak{E}.\end{array}\right\} \quad (7)$$

To compare these results with those derived from the electrical theory, we may take the general equation of monochromatic light on the electrical hypothesis from a paper in a former volume of this Journal. This equation, which with an unessential difference of notation may be written*

$$-\text{Pot}\,\ddot{\mathfrak{F}} - \nabla Q = 4\pi\Phi\mathfrak{F}, \quad (8)$$

was established by a method and considerations similar to those which have been used to establish equation (6), except that the ordinary law of electro-dynamic induction had the place of the new law of elasticity. $\mathfrak{F}$ is a complex vector representing the electrical displacement as a harmonic function of the time; Φ is a complex linear vector operator, such that $4\pi\Phi\mathfrak{F}$ represents the electromotive force necessary to keep up the vibration $\mathfrak{F}$. Q is a complex scalar representing the electrostatic potential, ∇Q the vector of which the three components are

$$\frac{dQ}{dx}, \quad \frac{dQ}{dy}, \quad \frac{dQ}{dz}.$$

Pot denotes the operation by which in the theory of gravitation the potential is calculated from the density of matter.† When it is applied as here to a vector, the three components of the result are to be calculated separately from the three components of the operand. $-\nabla Q$ is therefore the electrostatic force, and $-\text{Pot}\,\ddot{\mathfrak{F}}$ the electrodynamic force. In establishing the equation, it was not assumed that the electrical motions are *solenoidal*, or such as to satisfy the so-called "equation of continuity." We may now, however, make this assumption,

* See this Journal, vol. xxv, p. 114, equation (12).

† The symbol $-\text{Pot}$ is therefore equivalent to $4\pi\nabla^{-2}$, as used by Sir William Thomson (with a happy economy of symbols) at the last meeting of British Association to express the same law of electrodynamic induction, except that the symbol is here used as a vector operator. See Nature, vol. xxxviii, p. 571, *sub. init.*

since it is the extreme case of the electric theory which we are to compare with the extreme case of the elastic.

It results from the definitions of *curl* and ∇ that curl $\nabla Q = 0$. We may therefore eliminate Q from equation (8) by taking the curl. This gives

$$-\text{curl Pot } \ddot{\mathfrak{F}} = 4\pi \text{ curl } \Phi\mathfrak{F}, \tag{9}$$

Since curl curl and $\frac{1}{4\pi}$ Pot are inverse operators for solenoidal vectors, we may get rid of the symbol Pot by taking the curl again. We thus get

$$-\ddot{\mathfrak{F}} = \text{curl curl } \Phi\mathfrak{F}. \tag{10}$$

The conditions for the motion at the boundary between different media are easily obtained from the following considerations. Pot $\ddot{\mathfrak{F}}$ and Q are evidently continuous at the interface. Therefore the components parallel to the interface of ∇Q, and by (8) of $\Phi\mathfrak{F}$, will be continuous. Again, curl Pot $\ddot{\mathfrak{F}}$ is continuous at the interface, as appears from the consideration that curl Pot $\dot{\mathfrak{F}}$ is the magnetic force due to the electrical motions $\dot{\mathfrak{F}}$. Therefore, by (9), curl $\Phi\mathfrak{F}$ is continuous. The solenoidal condition requires that the component of $\mathfrak{F}$ normal to the interface shall be continuous.

The following quantities are therefore continuous at the interface:

$$\left.\begin{array}{ll} \text{the components parallel to the interface of} & \Phi\mathfrak{F}, \\ \text{the component normal to the interface of} & \mathfrak{F}, \\ \text{all components of} & \text{curl } \Phi\mathfrak{F}. \end{array}\right\} \tag{11}$$

Of these conditions, the two relating to the normal components of $\mathfrak{F}$ and curl $\Phi\mathfrak{F}$ are easily shown to result from the other four conditions, as in the analogous case in the elastic theory.

If we now compare in the two theories the differential equations of the motion of monochromatic light for the interior of a sensibly homogeneous medium, (6) and (10), and the special conditions for the boundary between two such media as represented by the continuity of the quantities (7) and (11), we find that these equations and conditions become identical, if

$$\mathfrak{F} = \Psi\mathfrak{E}, \tag{12}$$

$$\mathfrak{E} = \Phi\mathfrak{F}, \tag{13}$$

$$\Psi = \Phi^{-1}. \tag{14}$$

In other words, the displacements in either theory are subject to the same general and surface conditions as the forces re-

quired to maintain the vibrations in an element of volume in the other theory.

To fix our ideas in regard to the signification of Ψ and Φ, we may consider the case of isotropic media, in which these operators reduce to ordinary algebraic quantities, simple or complex. Now the *curl* of any vector necessarily satisfies the solenoidal condition (the so-called 'equation of continuity'), therefore by (6) $\Psi\mathfrak{E}$ and $\mathfrak{E}$ will be solenoidal. So also will $\mathfrak{F}$ and $\Phi\mathfrak{F}$ in the electrical theory. Now for solenoidal vectors

$$-\text{curl curl} = \frac{d^2}{dx^2}+\frac{d^2}{dy^2}+\frac{d^2}{dz^2}, \tag{15}$$

so that the equations (6) and (10) reduce to

$$\Psi\ddot{\mathfrak{E}}=\left(\frac{d^2}{dx^2}+\frac{d^2}{dy^2}+\frac{d^2}{dz^2}\right)\mathfrak{E}, \tag{16}$$

$$\ddot{\mathfrak{F}}=\left(\frac{d^2}{dx^2}+\frac{d^2}{dy^2}+\frac{d^2}{dz^2}\right)\Phi\mathfrak{F} \tag{17}$$

For a simple train of waves, the displacement, in either theory, may be represented by a constant multiplied by

$$e^{\iota(gt+ax+by+cz)} \tag{18}$$

Our equations then reduce again to

$$g^2\Psi\mathfrak{E}=(a^2+b^2+c^2)\mathfrak{E}, \tag{19}$$

$$g^2\mathfrak{F}=(a^2+b^2+c^2)\Phi\mathfrak{F}. \tag{20}$$

Hence,

$$\Psi^{-1}=\Phi=\frac{g^2}{a^2+b^2+c^2}. \tag{21}$$

The last member of this equation, when real, evidently expresses the square of the velocity of light. If we set

$$n^2=k^2\frac{a^2+b^2+c^2}{g^2}, \tag{22}$$

k denoting the velocity of light *in vacuo*, we have

$$n^2=k^2\Psi=k^2\Phi^{-1}. \tag{23}$$

When n^2 is positive, which is the case of perfectly transparent bodies, the positive root of n^2 is called the index of refraction of the medium. In the most general case, it would be appropriate to call n—or perhaps that root of n^2 of which the real part is positive—the (complex) index of refraction, although the terminology is hardly settled in this respect. A negative value of n^2 would represent a body from which light would be totally reflected at all angles of incidence. No such cases have been observed. Values of n^2 in which the coeffi-

cient of ϵ is negative, indicate media in which light is absorbed. Values in which the coefficient of ϵ is positive would represent media in which the opposite phenomenon took place.*

It is no part of the object of this paper to go into the details by which we may derive, so far as observable phenomena are concerned, Fresnel's law of double refraction for transparent bodies, as well as the more general law of the same character which relates to aeolotropic bodies of more or less opacity, and which differs from Fresnel's only in that certain quantities become complex, or Fresnel's laws for the intensities of reflected and refracted light at the boundary of transparent isotropic media, with the more general laws for the case of bodies aeolotropic or opaque or both. The principal cases have already been discussed on the new elastic theory in the *Philosophical Magazine*† and a farther discussion is promised. For the electrical theory, the case of double refraction in perfectly transparent media has been discussed quite in detail in this Journal,‡ and the intensities of reflected and refracted light have been abundantly deduced from the above conditions by various authors.§ So far as all these laws are concerned, the object of this paper will be attained, if it has been made clear, that the two theories, in their extreme cases, give identical results. The greater or less degree of elegance, or completeness, or perspicuity, with which these laws may be developed by different authors, should weigh nothing in favor of either theory.

The non-magnetic rotation of the plane of polarization, with the allied phenomena in aeolotropic bodies, lie in a certain sense outside of the above laws, as depending on minute quantities which have been neglected in this discussion. The manner in which these minute quantities affect the equations of motion on the electrical theory has been shown in a former paper,‖ where these phenomena in transparent bodies are treated quite at length. For the new theory, a discussion of this subject is promised by Mr. Glazebrook.

But the magnetic rotation of the plane of polarization, with the allied phenomena when an aeolotropic body is subjected to magnetic influence, fall entirely within the scope of the above equations and surface-conditions. The characteristic of this

* But ϵ might have been introduced into the equations in such a way that a positive coefficient in the value of n^2 would indicate absorption, and a negative coefficient the impossible case.

† Sir William Thomson, *loc. citat.* R. T. Glazebrook, *loc. citat.*

‡ Vol. xxiii. p. 262.

§ Lorentz, Schlömilch's Zeitschrift, vol. xxii, pp. 1–30 and 205–219; vol. xxiii, pp. 197–210; Fitzgerald, Phil. Trans., vol. clxxi, p. 691; J. J. Thomson, Phil. Mag. (V), vol. ix, p. 284; Rayleigh, Phil. Mag. (V), vol. xii, p. 81. Glazebrook, Proc. Cambr. Phil. Soc., vol. iv, p. 155.

‖ This Journal, vol. xxiii, p. 460.

case is that Ψ and Φ are not self-conjugate.* This is what we might expect on the electric theory from the experiments of Dr. Hall, which show that the operators expressing the relation between electro-motive force and current are not in general self-conjugate in this case.

In the preceding comparison, we have considered only the limiting cases of the two theories. With respect to the sense in which the limiting case is admissible, the two theories do not stand on quite the same footing. In the electric theory, or in any in which the velocity of the missing wave is very great, if we are satisfied that the compressibility is so small as to produce no appreciable results, we may set it equal to zero in our mathematical theory, even if we do not regard this as expressing the actual facts with absolute accuracy. But the case is not so simple with an elastic theory in which the forces resisting certain kinds of motion vanish, so far, at least, as they are proportional to the strains. The first requisite for any sort of optical theory is that the forces shall be proportional to the displacements. This is easily obtained in general by supposing the displacements very small. But if the resistance to one kind of distortion vanishes, there will be a tendency for this kind of distortion to appear at some places in an exaggerated form, and even to an infinite degree, however small the displacements may be in other parts of the field. In the case before us, if we suppose the velocity of the missing wave to be absolutely zero, there will be infinite condensations and rarefactions at a surface where ordinary waves are reflected. That is, a certain volume of ether will be condensed to a surface, and *vice versâ*. This prevents any treatment of the extreme case, which is at once simple and satisfactory. The difficulty has been noticed by Sir William Thomson, who observes that it may be avoided if we suppose the displacements infinitely small in comparison with the wave-length of the wave of compression. This implies a finite velocity for that wave. A similar difficulty would probably be found to exist (in the extreme case) with regard to the deformation of the ether by the molecules of ponderable matter, as the ether oscillates among them. If the statical resistance to irrotational motions is zero, it is not at all evident that the statical forces evoked by the disturbance caused by the molecules would be proportional to the motions. But this difficulty would be obviated by the same hypothesis as the first.

These circumstances render the elastic theory somewhat less convenient as a working hypothesis than the electric. They do not necessarily involve any complication of the equations of optics. For it may still be possible that this velocity of the

* See this Journal, vol. xxv, p. 113.

missing wave is so small that the quantities on which it depends may be set equal to zero in the equations which represent the phenomena of optics. But the mental processes by which we satisfy ourselves of the validity of our results (if we do not work out the whole problem in the general case of no assumption in regard to the velocity of the missing wave) certainly involve conceptions of a higher degree of difficulty on account of the circumstances mentioned. Perhaps this ought not to affect our judgment with respect to the question of the truth of the hypothesis.

Although the two theories give laws of exactly the same form for monochromatic light in the limiting case, their deviations from this limit are in opposite directions, so that if the phenomena of optics differed in any marked degree from what we would have in the limiting case, it would be easy to find an *experimentum crucis* to decide between the two theories. A little consideration will make it evident, that when the principal indices of refraction of a crystal are given, the intermediate values for oblique wave-planes will be less if the velocity of the missing wave is small but finite, than if it is infinitesimal, and will be greater if the velocity of the missing wave is very great but finite than if it is infinite.* Hence, if the velocity of the missing wave is small but finite, the intermediate values of the indices of refraction will be less than are given by Fresnel's law, but if the velocity of the missing wave is very great but finite, the intermediate values of the indices of refraction will be greater than are given by Fresnel's law. But the recent experiments of Professor Hastings on the law of double refraction in Iceland spar do not encourage us to look in this direction for the decision of the question.†

In a simple train of waves in a transparent medium, the potential energy, on the elastic theory, may be divided into two parts, of which one is due to that general deformation of the ether which is represented by the equations of wave-motion, and the other to those deformations which are caused by the interference of the ponderable particles with the wave-motion, and to such displacements of the ponderable matter as may be caused, in some cases at least, by the motion of the ether. If we write h for the amplitude, l for the wave-length, and p for the period, these two parts of the statical energy (esti-

* This may be more clear if we consider the stationary waves formed by two trains of waves moving in opposite directions. The case then comes under the following theorem:

"If the system undergo such a change that the potential energy of a given configuration is diminished, while the kinetic energy of a given motion is unaltered, the periods of the free vibrations are all increased, and conversely." See Lord Rayleigh's *Theory of Sound*, vol. i, p. 85.

† This Journal, vol. xxxiii, p. 60.

mated per unit of volume for a space including many wave-lengths) may be represented respectively by

$$\frac{\pi^2 B h^2}{l^2} \text{ and } \frac{b h^2}{4}.$$

The sum of these may be equated to the kinetic energy, giving an equation of the form

$$\frac{\pi^2 B h^2}{l^2} + \frac{b h^2}{4} = \frac{\pi^2 A' h^2}{p^2}. \qquad (24)$$

B is an absolute constant (the rigidity of the ether, previously represented by the same letter), A′ and b will be constant (for the same medium and the same direction of the wave-normal) except so far as the type of the motion changes, *i. e.*, except so far as the manner in which the motion of the ether distributes itself between the ponderable molecules, and the degree in which these take part in the motion, may undergo a change. When the period of vibration varies, the type of motion will vary more or less, and A′ and b will vary more or less.

In a manner entirely analogous,* the *kinetic* energy, on the electrical theory, may be divided into two parts, of which one is due to those general fluxes which are represented by the equations of wave-motions, and the other to those irregularities in the fluxes which are caused by the presence of the ponderable molecules, as well as to such motions of the ponderable particles themselves, as may sometimes occur. These parts of the kinetic energy may be represented respectively by

$$\frac{\pi F l^2 h^2}{p^2} \text{ and } \frac{\pi^2 f h^2}{p^2}.$$

Their sum equated to the potential energy gives

$$\frac{\pi F l^2 h^2}{p^2} + \frac{\pi^2 f h^2}{p^2} = \frac{G h^2}{4}. \qquad (25)$$

Here F is the constant of electrodynamic induction, which is unity if we use the electromagnetic system of units, f and G (like A′ and b) vary only so far as the type of motion varies.

We have the means of forming a very exact numerical estimate of the ratio of the two parts into which the statical energy is thus divided on the elastic theory, or the kinetic energy on the electric theory. The means for this estimate is afforded by the principle that the period of a natural vibration is stationary when its type is infinitesimally altered by any constraint.† Let us consider a case of simple wave motion, and suppose the period to be infinitesimally varied, the wave-

* See this Journal, vol. xxii, p. 262.

† See Lord Rayleigh's *Theory of Sound*, vol. i, p. 84. The application of the principle is most simple in the case of stationary waves.

length will also vary, and presumably to some extent the type of vibration. But, by the principle just stated, if the ether or the electricity could be constrained to vibrate in the original type, the variations of l and p would be the same as in the actual case. Therefore, in finding the differential equation between l and p, we may treat b and A′ in (24) and f and G in (25) as constant, as well as B and F. These equations may be written

$$4\pi^2 \mathrm{B}\frac{p^2}{l^2} + bp^2 = 4\pi^2 \mathrm{A}',$$

$$\pi \mathrm{F}\frac{l^2}{p^2} + \frac{\pi^2 f}{p^2} = \tfrac{1}{4}\mathrm{G}.$$

Differentiating, we get

$$4\pi^2 \mathrm{B}\, d\frac{p^2}{l^2} = -\, b\, d(p^2),$$

$$\pi \mathrm{F}\, d\frac{l^2}{p^2} = -\, \pi^2 f\, d(p^{-2});$$

or

$$4\pi^2 \mathrm{B}\,\frac{p^2}{l^2}\, d\,\log\frac{p^2}{l^2} = -\, b\, p^2\, d\log p^2,$$

$$\pi \mathrm{F}\frac{l^2}{p^2}\, d\,\log\frac{l^2}{p^2} = -\,\frac{\pi^2 f}{p^2}\, d\,\log p^{-2}.$$

Hence, if we write V for the wave-velocity (l/p), n for the index of refraction, and λ for the wave-length *in vacuo*, we have for the ratio of the two parts into which we have divided the potential energy on the elastic theory,

$$\frac{bh^2}{4} \div \frac{\pi^2 \mathrm{B}h^2}{l^2} = \frac{d\log \mathrm{V}}{d\log p} = -\,\frac{d\log n}{d\log \lambda}, \qquad (26)$$

and for the ratio of the two parts into which we have divided the kinetic energy on the electrical theory,

$$\pi^2 \frac{fh^2}{p^2} \div \frac{\pi \mathrm{F} l^2 h^2}{p^2} = \frac{d\log \mathrm{V}}{d\log p} = -\,\frac{d\log n}{d\log \lambda}. \qquad (27)$$

It is interesting to see that these ratios have the same value. This value may be expressed in another form, which is suggestive of some important relations. If we write U for what Lord Rayleigh has called the velocity of a group of waves,*

$$\frac{\mathrm{U}}{\mathrm{V}} = 1 - \frac{d\log \mathrm{V}}{d\log l},$$

$$\frac{d\log \mathrm{V}}{d\log l} = \frac{\mathrm{V}-\mathrm{U}}{\mathrm{V}},$$

$$\frac{d\log \mathrm{V}}{d\log p} = \frac{\mathrm{V}-\mathrm{U}}{\mathrm{U}}. \qquad (28)$$

* See his *Note on Progressive Waves*, Proc. Lond. Math. Soc., vol. ix, No. 125, reprinted in his *Theory of Sound*, vol. ii, p. 297.

It appears, therefore, that in the elastic theory that part of the potential energy which depends on the deformation expressed by the equations of wave-motion, bears to the whole potential energy the same ratio which the velocity of a group of waves bears to the wave-velocity. In the electrical theory, that part of the kinetic energy which depends on the motions expressed by the equations of wave-motion bears to the whole kinetic energy the same ratio.

Returning to the consideration of equations (26) and (27), we observe that in transparent bodies the last member of these equations represents a quantity which is small compared with unity, at least in the visible spectrum, and diminishes rapidly as the wave-length increases. This is just what we should expect of the first member of equation (27). But when we pass to equation (26), which relates to the elastic theory, the case is entirely different. The fact that the kinetic energy is affected by the presence of the ponderable matter, and affected differently in different directions, shows that the motion of the ether is considerably modified. This implies a distortion, superposed upon the distortion represented by the equations of wave-motion, and very much greater, since the body is very fine-grained as measured by a wave-length. With any other law of elasticity, we should suppose that the energy of this superposed distortion would enormously exceed that of the regular distortion represented by the equations of wave-motion. But it is the peculiarity of this new law of elasticity that there is one kind of distortion, of which the energy is very small, and which is therefore peculiarly likely to occur. Now if we can suppose the distortion caused by the ponderable molecules to be almost entirely of this kind, we may be able to account for the smallness of its energy. We should still expect the first member of (26) to increase with the wave-length, on account of the factor l^2, instead of diminishing, as the last member of the equation shows that it does. We are obliged to suppose that b, and therefore the type of the vibrations, varies very rapidly with the wave-length, even in those cases which appear farthest removed from anything like selective absorption.

The electrical theory furnishes a relation between the refractive power of a body and its specific dielectric capacity, which is commonly expressed by saying that the latter is equal to the square of the index of refraction for waves of infinite length. No objection can be made to this statement, but the great uncertainty in determining the index for waves of infinite length by extrapolation prevents it from furnishing any very rigorous test of the theory. Yet, as the results of extrapolation in some cases agree strikingly with the specific dielec-

tric capacity, although in other cases they are quite different, the correspondence is generally regarded as corroborative, in some degree, of the theory. But the relation between refractive power and dielectric capacity may be expressed in a form which will furnish a more rigorous test, as not involving extrapolation.

We have seen on page 140 how we may determine numerically the ratio of the two first terms of equation (25). We thus easily get the ratio of the first and last term, which gives

$$\frac{\mathrm{G}h^2}{4} = \frac{d \log l}{d \log \lambda} \frac{\pi \mathrm{F} l^2 h^2}{p^2}. \tag{29}$$

In the corresponding equation for a train of waves of the same amplitude and period *in vacuo*, l becomes λ, F remains the same and for G we may write G′. This gives

$$\frac{\mathrm{G}'h^2}{4} = \frac{\pi \mathrm{F} \lambda^2 h^2}{p^2}. \tag{30}$$

Dividing, we get

$$\frac{\mathrm{G}}{\mathrm{G}'} = \frac{d \log l}{d \log \lambda} \frac{l^2}{\lambda^2} = \frac{d (l^2)}{d (\lambda^2)}. \tag{31}$$

Now G′ is the dielectric elasticity of pure ether. If K is the specific dielectric capacity of the body which we are considering, G′/K is the dielectric elasticity of the body and G′/2K is the potential energy of the body (per unit of volume), due to a unit of ordinary electrostatic displacement. But $\mathrm{G}h^2/4$ is the potential energy in a train of waves of amplitude h. Since the average square of the displacement is $h^2/2$, the potential energy of a unit displacement such as occurs in a train of waves is G/2. Now in the electrostatic experiment the displacement distributes itself among the molecules so as to make the energy a minimum. But in the case of light the distribution of the displacement is not determined entirely by statical considerations. Hence

$$\frac{\mathrm{G}}{2} \geqq \frac{\mathrm{G}'}{2\mathrm{K}}, \tag{32}$$

$$\mathrm{K} \geqq \frac{\mathrm{G}'}{\mathrm{G}},$$

and

$$\mathrm{K} \geqq \frac{d (\lambda^2)}{d (l^2)}. \tag{33}$$

It is to be observed that if we should assume for a dispersion-formula

$$n^{-2} = a - b\lambda^{-2}, \tag{34}$$

$1/a$, which is the square of the index of refraction for an infinite wave-length, would be identical with the second member of (33).

Another similarity between the electrical and optical properties of bodies consists in the relation between conductivity and opacity. Bodies in which electrical fluxes are attended with absorption of energy absorb likewise the energy of the motions which constitute light. This is strikingly true of the metals. But the analogy does not stop here. To fix our ideas, let us consider the case of an isotropic body and circularly polarized light, which is geometrically the simplest case, although its analytical expression is not so simple as that of plane-polarized light. The displacement at any point may be symbolized by the rotation of a point in a circle. The external force necessary to maintain the displacement $\mathfrak{F}$ is represented by $n^{-2}\mathfrak{F}$. In transparent bodies, for which n^{-2} is a positive number, the force is radial and in the direction of the displacement, being principally employed in counterbalancing the dielectric elasticity, which tends to diminish the displacement. In a conductor n^{-2} becomes complex, which indicates a component of the force in the direction of $\dot{\mathfrak{F}}$, that is, tangential to the circle. This is only the analytical expression of the fact above mentioned. But there is another optical peculiarity of metals, which has caused much remark, viz: that the real part of n^2 (and therefore of n^{-2}) is negative, i. e., the radial component of the force is directed towards the center. This inwardly directed force, which evidently opposes the electrodynamic induction of the irregular part of the motion, is small compared with the outward force which is found in transparent bodies, but increases rapidly as the period diminishes. We may say, therefore, that metals exhibit a second optical peculiarity,—that the dielectric elasticity is not prominent as in transparent bodies. This is like the electrical behavior of the metals, in which we do not observe any elastic resistance to the motion of electricity. We see, therefore, that the complex indices of metals, both in the real and the imaginary part of their inverse squares, exhibit properties corresponding to the electrical behavior of the metals.

The case is quite different in the elastic theory. Here the force from outside necessary to maintain in any element of volume the displacement $\mathfrak{E}$ is represented by $n^2\ddot{\mathfrak{E}}$. In transparent bodies, therefore, it is directed toward the center. In metals, there is a component in the direction of the motion $\dot{\mathfrak{E}}$, while the radial part of the force changes its direction and is often many times greater than the opposite force in transpar-

ent bodies. This indicates that in metals the displacement of the ether is resisted by a strong elastic force, quite enormous compared to anything of the kind in transparent bodies, where it indeed exists, but is so small that it has been neglected by most writers, except when treating of dispersion. We can make these suppositions, but they do not correspond to anything which we know independently of optical experiment.

It is evident that the electrical theory of light has a serious rival, in a sense in which, perhaps, one did not exist before the publication of Sir William Thomson's paper in November last.* Nevertheless, neither surprise at the results which have been achieved, nor admiration for that happy audacity of genius, which, seeking the solution of the problem precisely where no one else would have ventured to look for it, has turned half a century of defeat into victory, should blind us to the actual state of the question.

It may still be said for the electrical theory, that it is not obliged to invent hypotheses,† but only to apply the laws furnished by the science of electricity, and that it is difficult to account for the coincidences between the electrical and optical properties of media, unless we regard the motions of light as electrical. But if the electrical character of light is conceded, the optical problem is very different from anything which existed in the time of Fresnel, Cauchy, and Green. The third wave, for example, is no longer something to be gotten rid of *quocunque modo*, but something which we must dispose of in accordance with the laws of electricity. This would seem to rule out the possibility of a relatively small velocity for the third wave.

* "Since the first publication of Cauchy's work on the subject in 1830, and of Green's in 1837, many attempts have been made by many workers to find a dynamical foundation for Fresnel's laws of reflexion and refraction of light, but all hitherto ineffectually." Sir William Thomson, *loc. citat.*

"So far as I am aware, the electric theory of Maxwell is the only one satisfying these conditions [of explaining at once Fresnel's laws of double refraction in crystals and those governing the intensity of reflexion when light passes from one isotropic medium to another]." Lord Rayleigh, *Phil. Mag.*, September, 1888.

† Electrical motions in air, since the recent experiments of Professor Hertz, seem to be no longer a matter of hypothesis. We can hardly suppose that the case is essentially different with the so-called vacuum. The theorem that the electrical motions of light are solenoidal, although it is convenient to assume it as a hypothesis and show that the results agree with experiment, need not occupy any such fundamental position in the theory. It is in fact only another way of saying that two of the constants of electrical science have a certain ratio (infinity). It would be easy to commence without assuming this value, and to show in the course of the development of the subject that experiment requires it, not of course as an abstract proposition, but in the sense in which experiment can be said to require any values of any constants, that is, to a certain degree of approximation.

Art. XVII.—*The Geology of Fernando de Noronha.* Part I; by John C. Branner. With a map, Plate V.

The island of Fernando de Noronha has never attracted much attention, owing to its small area, its want of commercial importance, and its somewhat forbidding character as a landing place, and partly also to its having long been used as a place of exile and punishment for criminals. Prior to the visit of the writer the geologic observations made upon the island of Fernando were very few; the only ones worthy of especial notice being those of Charles Darwin in 1832, made while on the voyage of the Beagle and published in his Geological Observations in 1844, and a few observations made, along with the collection of specimens, when the Challenger touched here in 1873. A careful survey would have been made by the Challenger party had permission been given by the Brazilian officers in charge; but owing to the care exercised in the supervision of the convicts and to a misapprehension of the objects of the survey, this permission was unfortunately withheld.

In 1876 I visited Fernando as a member of the Imperial Geological Survey of Brazil, and the following brief notes are the first to be published giving any of the results of my observations upon its geology.

With the accompanying map the reader will scarcely need any observations upon the geography of this group of islands, while the illustrations will convey a sufficiently clear idea of the surface features of the place to dispense with detailed descriptions of topography.

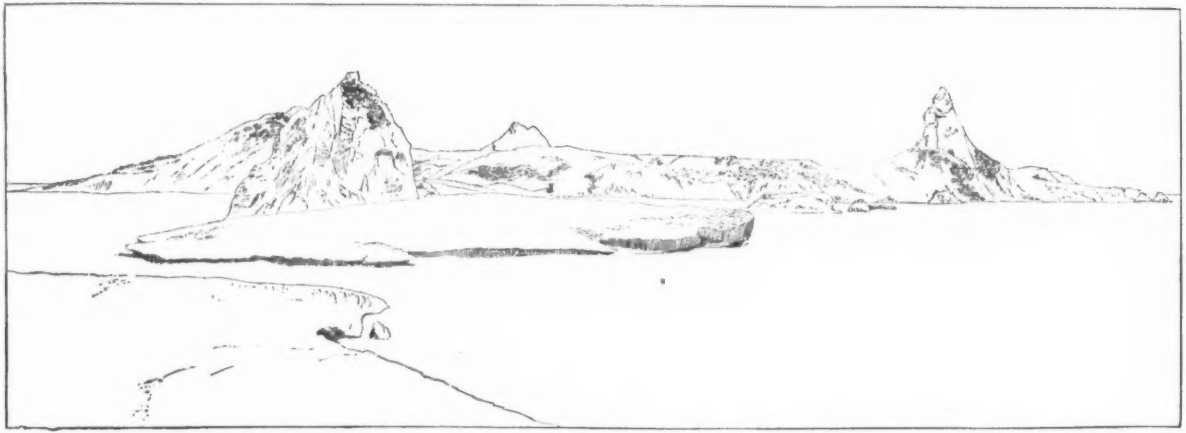
The form of the ocean's bottom around this island, however, is worthy of note as indicating the relations of the group to other islands and to the Brazilian mainland. For the facts bearing upon this subject we are indebted to the deep-sea soundings of the Challenger expedition. It was formerly supposed that Fernando was simply the original northeastern extremity of the South American continent, now separated from Cape St. Roque by a shallow channel. The deep sea soundings have shown, however, that the Fernando group is an isolated one, and that the channels separating it from the Rocas, from St. Paul's Rock and from the Brazilian mainland, are profound ones. The channel between Fernando and St. Paul's Rock is more than 14,000 feet deep, while between Fernando and the Brazilian mainland the depth is over 13,000 feet. To the northeast, six miles from the island, the sound

ings show a depth of more than 6,000 feet, while to the southeast, at the same distance, the depth is 3150 feet, and at twelve miles, 4920 feet. This group of islands, therefore, rises abruptly from the ocean's floor. The currents and surf that strike it from the east are unchecked by shallows on that side, so that it receives the full force of the waves and is consequently being cut away at a rapid rate.

The island is of volcanic origin, there being no sedimentary rocks upon it. The volcano which once existed here ceased action long ago, and the powerful surf which constantly beats upon the island has since cut away the cone, and is now fast diminishing the remnants of the original island. Moreover, the usual chemical processes of disintegration, hastened and deepened here by a very great precipitation falling upon rocks highly heated by exposure to a tropical sun, has covered the interior of the island with a deep soil mingled with rock fragment which, together, obscure the geological details over the main body of the island. Its original lofty central portion has gradually yielded to these disintegrating influences till only the great Peak and its smaller companions remain to suggest the former elevation of the group. A large portion of the island is now under cultivation, and the loose blocks, which might otherwise have been of some service in suggesting, at least, the distribution of the rocks, have been gathered from the fields and built up in stacks or stone walls, or used to make roads or houses. The lands that formerly sloped at a low angle into the sea have been encroached upon, cut down and swept away by the ocean currents until the island is now walled in for the most part by high, precipitous cliffs; the ancient sandy beaches which at one time bordered its southeastern shores, and which were probably fringed by coral reefs, have been almost completely obliterated. The more rapid destruction along the shores and the slower weathering of the interior brings into close proximity two topographic types, and almost any view which includes both shore and inland topography shows the more graceful lines of the old topography in strong contrast with the newer, bolder, and more angular cliffs and escarpments made by the steady encroachments of the sea upon the land.

The best, and almost the only, good rock exposures are about the shores; but many of these are difficult or impossible of access on account of the lack of boating facilities at the island, and because of the violent surf which so generally prevails. In addition, the rocks are so broken, faulted, and thrown into confusion, that it must be confessed my study of the place was far from satisfactory. I endeavored especially to construct an accurate map of the island, and to collect typical rock speci-

I.



Sketch of the Island of Fernando de Noronha taken from Ilha Rapta.

mens. The results of these endeavors are to be seen in the map published herewith—which does not differ materially from the French map published in 1873—and in the petrographic work kindly done by Dr. George H. Williams. The drawings are made from sketches and photographs taken by the writer. Unfortunately the dry, sensitive plates so universally and successfully used nowadays for photography were not then to be had, and the clumsy apparatus I was obliged to use prevented my obtaining some very desirable views.

The work which has hitherto been done upon the rocks of Fernando will be referred to by Dr. Williams in his part of the present paper. I wish to add, however, that the statement made by Dr. Alexander Rattray* to the effect that granite forms part of the peak and of "other hills, headlands and rocks" is erroneous. There is no granite on the island, so far as I was able to discover.

Amphibole-trachyte occurs at the base of Atalaia Grande and to the west of it. The beds from which the specimen (No. 10) was taken are soft and appear to be decaying rapidly. The exposure has a northeast and southwest trend at this place. The same kind of rock (No. 121) occurs on the east side and about the base of the Morro Francez where it is traversed by dykes of hornblende-augite trachyte (?) (No. 129). The soft whitish and cream-colored amphibole-trachyte which occurs at the bases of some of the hills and notably about Atalaia Grande is called *tauá* by many of the inhabitants. This is a Tupi word however, meaning clay, and is the one given on the Brazilian mainland to clays of any kind, and is doubtless applied to these soft rocks on account of their slight resemblance to hard clays.

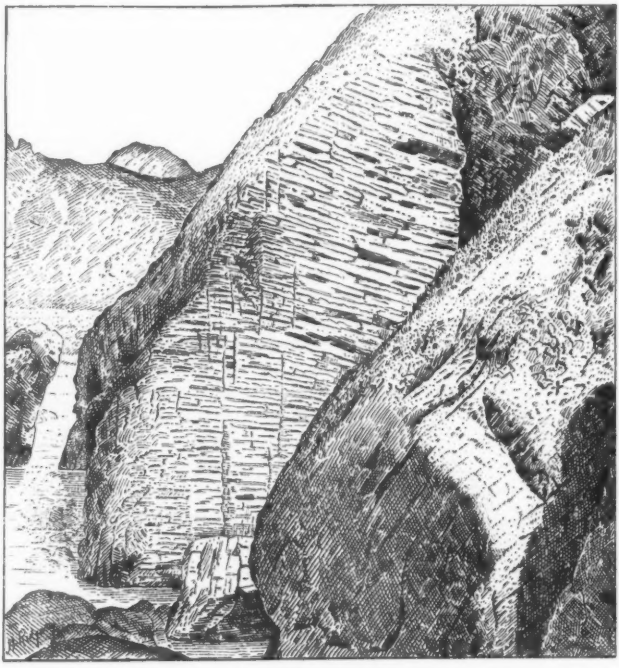
Hyalotrachyte occurs in several places. The principal localities are between the mouth of the stream flowing into the Bahia do Sueste and the old Fortaleza dos Leões. The rock (No. 19) is white and almost as soft as chalk, and breaks into irregular lumps. Here and there through the mass are lead-colored patches. It is supposed by the people on the island to be kaolin, and samples of it are said to have been taken to Europe to be tested for the manufacture of porcelain.

Phonolite.—Most of the isolated topographic prominences in the eastern portion of the island, with the exception of the Morro Francez, are composed either wholly or principally of phonolite, while its lower elevations are of some variety of basalt, loose fragments of nepheline-dolerite being of frequent occurrence about the fields on the plateau above the village. These prominences are the Peak and the southwestern prolongation of the hill from which it rises, the Pedra da Conceição,

* Jour. Roy. Geog. Soc., vol. xlii, 1872, p. 43.

a small peninsula northeast of the village, the Sella á Gineta,* the summit and southeast face of Atalaia Grande down to the water's edge, and to all appearances the Alatainha or Atalaia Piquena, and the Morro do Sueste. No phonolite was found in the western portion of the island. In all cases, excepting that of the Pedra da Conceição, these phonolites have the appearance of having been injected as dykes into older rocks.

2.



Phonolite columns of Atalaia Grande.

They seem to have cooled irregularly, but for the most part, from the sides. The older and more soluble surrounding rocks have, of course, been removed by denudation. Mr. Darwin says of such masses of phonolite that they have probably been formed by "the injection of fluid feldspathic lava into yielding strata."† In all the cases mentioned above, the rocks have a

*This island was not visited by the writer. As seen from Ilha Raza and Ilha Rapta, its rock had the appearance of phonolite and was so regarded. The examples collected by the Challenger party show beyond question that this supposition was correct.

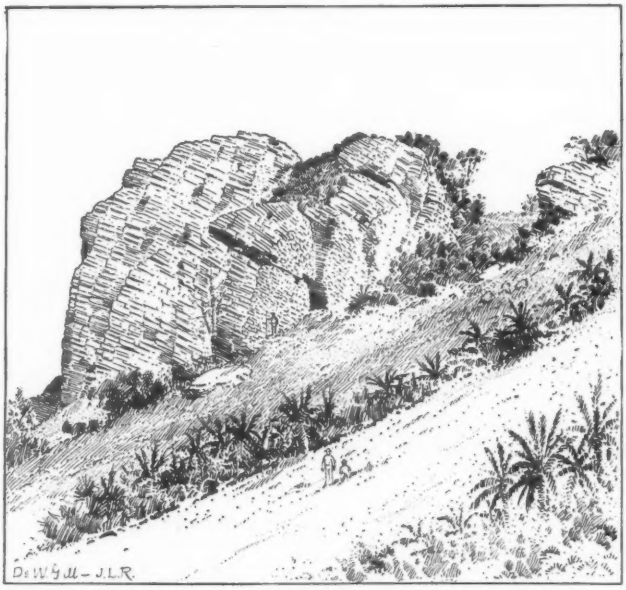
† Geological Observations, second edition p. 27.

columnar structure either very plainly or partially developed. The somewhat irregular columns lie for the most part horizontally, as is well shown in the dyke exposed at the Horta do Pico, southwest of the Peak. On the southeast side of the Atalaia Grande the columns are nearly horizontal, with a tendency to radiation from the center of the hill. Specimen No. 5 is from the nearly horizontal columns of phonolite exposed on the southwest side of the Atalaia Grande. Similar columns appear to form the whole south face of this peak, and are well exposed near its base where they are washed by the surf. As the peak is ascended the columns have a northward dip which increases toward the summit, so that a north-south section through the Atalaia Grande would expose the fan-like radiation of the columns above mentioned. The preceding cut, from a photograph of an exposure on the south side of Atalaia Grande, fig. 2, illustrates this point. No. 40 is from the summit of Atalaia Grande. Nos. 41 and 42 are from a loose block about 4×3×2 feet, found between Atalaia Grande and the Morro do Meio, the hill lying immediately north of it. This rock was not found in place on the island. It splits readily into slabs very like the phonolites from the Pedra da Conceição.

In the Sella á Gineta, fig. 4, the columns of phonolite are imperfect and vary somewhat in direction. Seen from São José some of the columns curve from a horizontal position on the left both upward and downward toward the right, radiating from a horizontal axis. In the Peak too, the direction of the columns varies in some cases as much as fifty degrees. The lowest rocks of the Peak exposed in place are the irregular columns upon its eastern side. The colums are here very nearly vertical; but higher up even upon this side, they twist and bend to the northeast and thus form the overhanging projection which is so remarkable a feature of this great rock. The curving of these columns prevents the falling of the most picturesque part of the Peak.* On its western side the columns stand at various angles with the meridian, and usually at a high angle with the horizon. Their direction and position, as well as the character of the rocks, leads to the conclusion that the Peak is part of a great dyke, the only remnants of which now exposed are the upper portions of the Peak itself, and the columns at the Horta do Pico, a short distance to the southwest. Specimens 51, 52 and 88 are from the highest accessible part of the Peak on its southwest

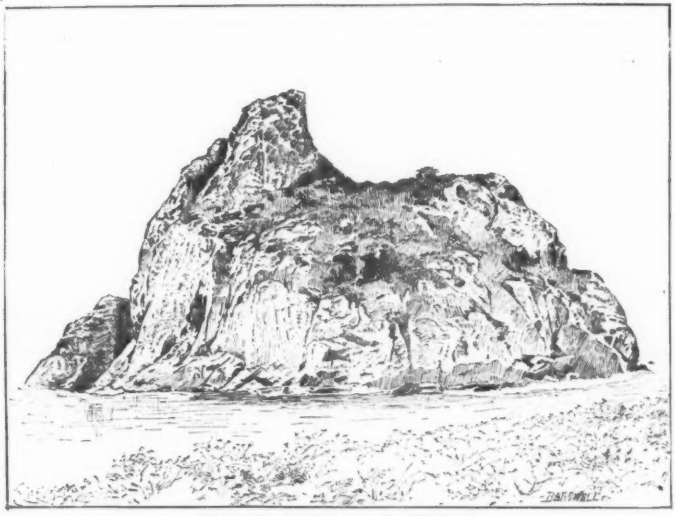
* Mr. Darwin calls attention to the disposition of phonolites to take on grotesque shapes. (Geological Observations, second ed., pp. 97–8). On Fernando these grotesque shapes of phonolite peaks are due to columnar structure when the axes of the columns change their directions. For a discussion of the curving and radiating of columns of igneous rocks see J. P. Iddings in Am. Jour. Sci., May, 1886, and Professor T. G. Bonney in Quart. Jour. Geol. Soc., vol. xxxii, 1876.

3.



Dyke of phonolite, near the Peak.

4



The Sella á Gineta or St. Michael.

side. The rocks of the summit are rudely columnar as is shown in the accompanying cut. The ledge just northwest of the Horta do Pico, fig. 3, shows the columnar structure of phonolite better perhaps than any other exposure upon the island. In most of these phonolites the metallic sound produced by striking with a hammer is very marked, especially when a somewhat thin slab is separated from the mass. From this peculiarity the Brazilians frequently call this rock "pedra de toque," which is the equivalent of our word "clinkstone."

The Peak is the most striking landmark in the South Atlantic ocean; it is 1000 feet high,* with the upper portion perpendicular or overhanging in such a manner as to make the summit quite inaccessible. The few drawings of this peak that have been published are taken from the same point—the anchorage—and even the best of them, that in the Challenger reports, conveys but a poor idea of its grandeur. Seen from other points it presents a striking variety of outlines.

It would be interesting to know whether this peak had undergone any marked changes since the discovery of the island in 1503, but unfortunately we have no detailed description of it as it appeared at that time, and the oldest drawing, that made by Ulloa in 1745, is clearly too imperfect to be trustworthy. It is evident, however, to one on the ground, that it is being slowly thrown down under the combined influence of sun and rain and the daily changes of temperature. Climbing up the accumulation of talus that slopes down from the base of the solid part of the peak to the seashore, it is noticeable that this material, loose as it is, stands at an angle of unstable equilibrium, and when disturbed in any way, miniature avalanches of loose stones slide down the slope, sometimes a hundred feet or more. Wherever this debris is stable there is sufficient soil upon it to support vegetation; and it is thus covered here and there with small tomato plants that have escaped from cultivation. In many places it was noticed that these plants were freshly broken and bruised by fragments that had fallen from the peak above.

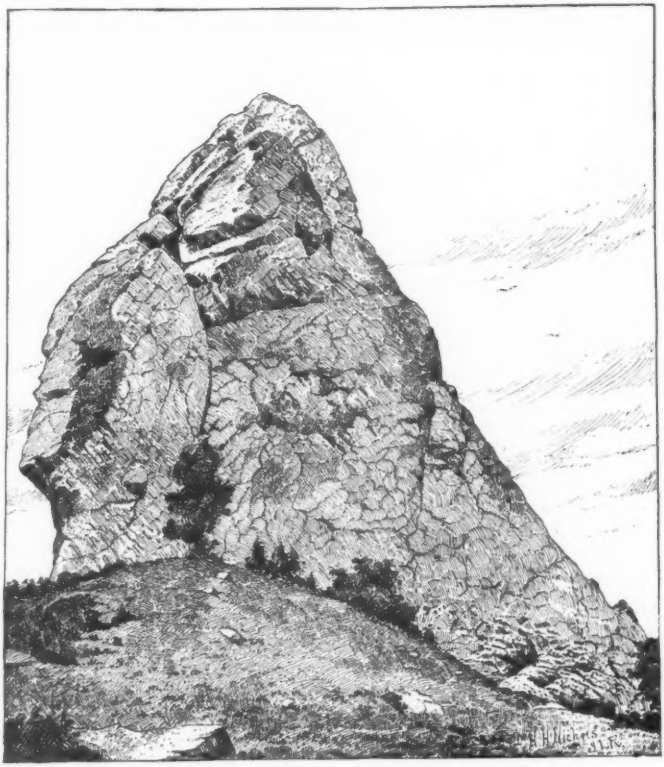
From top to bottom two great joints divide the Peak into three vertical sections. Into these crevices fall fragments of stone, which, heated and expanded during the day by the powerful rays of the sun, and cooled and contracted by the cool rains, or at night by radiation, wedge themselves deeper and deeper into the crevices and thus push off pieces large and small. Some years ago, no one seemed to know how many, the little fort near the base of the peak was almost completely demolished by a great mass of rock that fell from the Peak and rolled

* My own triangulation makes its height above tide 332 meters. Mouchez gives it at 305 meters.

down its sloping base. On another occasion, a convict, who had a little garden close under one side of the rock, found it one morning buried beneath a heap of stones.

From the east or northeast the upper portion of the Peak presents the rude outlines of a human face. Fig. 5 is made from a photograph taken looking up from the beach.

5.



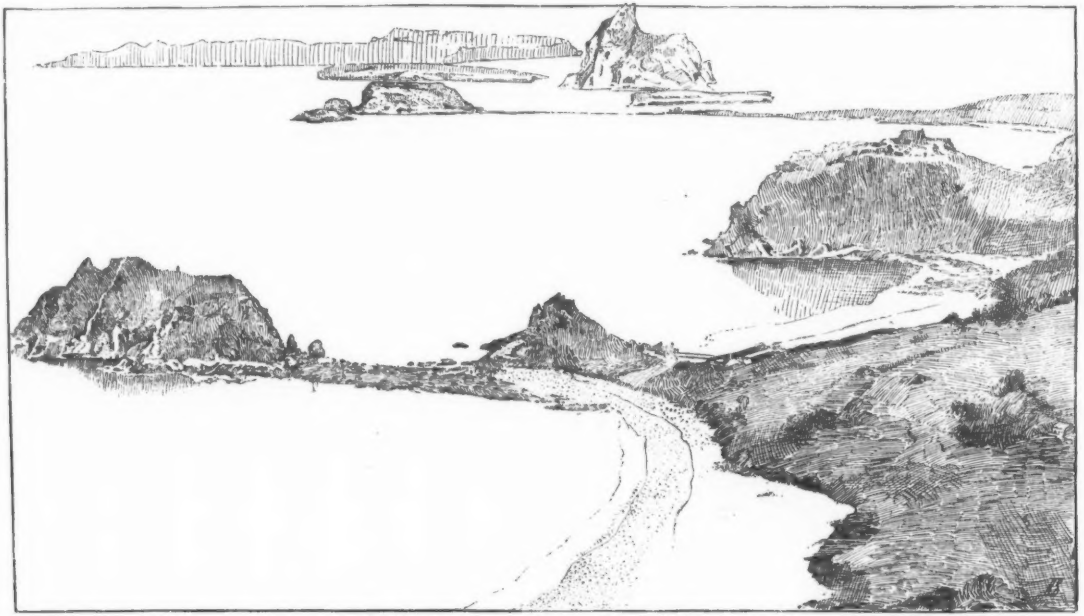
The Phonolite Peak of Fernando de Noronha, from the beach.

Slaty structure in phonolite.—The Pedra da Conceição is, at high tide, a small island of bare rock just west of the Praia do Cachorro, the landing place next the village; it has steep rugged sides and summit like a steep gothic roof. The place is shown in the left foreground of the following figure 6.

Most of the specimens collected at this locality were taken upon the south end or else upon the summit of this rock.

This locality is not included among those of the columnar phonolite. Mr. Darwin, in his "Geological Observations," remarks upon the occurrence near the base of the peak of slaty phonolite with cleavage. This peculiarity is very marked at the Pedra da Conceição, the rocks dipping sharply to the southwest, and having upon that side surfaces so flat and steep that I was able to hold my place only by clambering along its ridge. This is probably the locality to which Mr. Darwin refers. The rock splits readily into comparatively smooth slabs. A somewhat similar structure was observed in loose fragments found between the Morro do Meio and Atalaia Grande. (Nos. 40 and 42).

Basalts.—Rocks of a basaltic type form the great body of Fernando de Noronha. They occur in all portions of the island, and in masses of all shapes and sizes from thin veins to broad sheets. It was not observed, however, in any of the prominent isolated peaks, like the phonolite, yet nepheline-basalt was found on the summit of the Morro Francez, and augitite in the tuffs upon the east side of that hill. It occurs about the bases of the phonolite peaks, forming the body of Ilha Rapta, São José, Morro Redondo, and the cape near the phonolite peak of the Sella á Gineta. Rocks of basaltic type (limburgite) occur about the base of the Atalaia Grande and along the shores west of the peak. The Dois Irmãos appear to be made up of basalt, and so also the Laja Cape between the Atalainha and Morro Branco. In none of these cases, however, was I able to determine satisfactorily the relations of the basalt and phonolite to each other. Perhaps the most striking exposures of these rocks are to be seen upon the island of São José. The surf has here removed all the débris and uncovered columns of extremely hard nepheline-basanite (No. 31), which are best exposed upon the north side of the island, where a length of about fifty feet may be seen. This rock forms the greater part of São José and the two small adjoining islands, Pedra Furada and Ilha Redonda. In each case the columnar basalt forms the lower part of the island, and massive basalt the upper, while São José is further capped by a bed of the calcareous sandstone like that of which Ilha Raza is made. The columns of São José are usually bent. They vary in size and shape, as well as in position, but are usually hexagonal and about one foot in diameter, and break off in sections from one to four feet in length. The best exposure of the columns is on the eastern side of the island, where they are visible, however, only from the water. Many of them contain irregular masses of peridotite (No. 34) almost as large as one's fist. The broken columns are rolled by the surf upon the beach where they eventually form great black cobbles.



Looking north-east from the base of the Peak.

Ilha Rapta, the most northeastern of this group of islands, appears to be made up for the most part of basalt, these rocks forming its highest portion and its eastern and western extremities. At its east end the basalt is rudely columnar along steep shores 120 feet high; but generally there is a broken slope to the sea, covered, above the reach of the waves, with talus and earth. The western point, about the Espigão, is composed of nepheline-basalt (No. 72.)

The slender neck forming the northeastern promonotory of the main island, appears to be of basalt. The weathering of the rocks at the exposures upon this neck, and especially upon the southeast side, is characterized by extensive exfoliation and a consequent disintegration of the body of the rock walls into great, black, approximately round bowlders. As these masses lie in place they have the appearance of a gigantic rude stone wall built of black bowlders of various sizes. When they fall and come within the reach of the waves, though excessively hard, they are soon smoothed and rounded. The beach on the north side of this neck is covered by vast numbers of these black rounded stones, here facetiously known as "*corações de negro*"—negro hearts. Large blocks of nepheline-basalt (No. 45) cover the summit of the Morro Francez.

It seems probable that, with a few exceptions, the basaltic rocks are continuous from the extreme northeast point of the main island along its eastern and southern side to the bay next east of the Atalaia Grande, though but few of the specimens collected upon this portion of the island seem to have been preserved. It should be mentioned, however, that the great deposit of tuff which forms the higher portions of the shore, just east of the Morro Francez, contains loosely consolidated fragments of many varieties of rocks, among which are augitite (No. 115). The next extensive exposure of basalt (nepheline-basalt) is in the horizontal beds which form the southwest shore of the island from the cape at the Laja just west of the Bahia do Sueste to the Morro Branco, a distance of more than a mile. These basalts have the appearance, from a distance, of being horizontally stratified sedimentary rocks. The uppermost bed along this escarpment is of nepheline-basalt (No. 27), while the underlying beds resemble this in gross structure. (Nos. 28, 29, 30). The lower beds contain amygdaloidal cavities, as do also some of the basalts about the eastern extremity of the main island, notably at the mouth of the stream called Cuyeira.

Some of the rocks of the basaltic type occur next the base of Atalaia Grande on the south side, but on account of the soil which covers this part of the island it was not possible to determine satisfactorily their relations to the phonolites which

make up the body of the hill. The limburgite (No. 14) of the west base of Atalaia Grande forms a dyke either in, or west of and adjacent to, the amphibole trachyte (No. 10) mentioned elsewhere. Inasmuch as the eastern side of Atalaia Grande is exposed in one place down to the water's edge and is seen to be composed entirely of phonolite, these dykes of trachyte and limburgite are probably exterior to the body of the hill. Limburgite (No. 65) was found also in the peak of volcanic tuff which rises upon the narrow neck connecting the Sapato with the island. It there occurs associated with travertine (No. 66) and volcanic bombs. (Nos. 3 and 58). The two small isolated rocks known as the "Dois Irmãos" are not accessible, but as seen from the main island they have the appearance of being composed entirely of rudely columnar basalt.

Volcanic bombs (No. 48) occur in situ on the northern and near the summit of the Morro Francez. The east side of this hill, where it slopes down to the sea, is much checkered by dykes varying in thickness from two feet to eight, which cross each other at all angles. The bench of hard rock which skirts the base of the hill, and which is uncovered at low tide, varies in width from zero to three hundred and fifty feet. On its outer margin it is bordered by calcareous formations. On this bench the dykes are beautifully displayed at low tide. Immediately east of Capim Azul, a cliff more than 300 feet high is composed almost entirely of volcanic bombs and tuffs in beds dipping to the south at a high angle, and capped by jointed basalt. In size these bombs vary from that of a pin's head to the size of a bushel. Volcanic bombs occur also in the tuffs about the western end of the island, but they are nowhere so abundant or of such size as at the cliffs of Capim Azul.

Tuffs.—Tuffs occur about the northern and eastern sides of the Morro Francez, but are especially abundant about the western end of the island, where some of the beds are more than one hundred and fifty feet thick.

From the east side of the Morro Francez near the Pontinha are heavy beds of loosely consolidated tuff (No. 118), consisting of a mixture of angular fragments of rocks of many kinds which vary in size up to that of a millstone and larger; the beds slope down to the immediate beach of solid rock. This loose material is unlike the basaltic tuff of the western end of the island; it is greenish gray and without any appearance of stratification, while that of the Sapato and Capim Azul is more or less stratified and brownish.

The cliffs about Barro Vermelho and for some distance along the south side of the island, extending from the bed of volcanic bombs at Capim Azul to or near the Portão, are of some form of tuff (No. 62). The rock is soft and reddish, and

forms upon decomposition a deep red earth which gives name to this part of the island—"Barro Vermelho," red mud.

The Portão.—The extreme western portion of the island lying west of the Portão Grande is known as the Sapato (the shoe). This is one of the most interesting and impressive places on Fernando. The waves have cut away the soft beds

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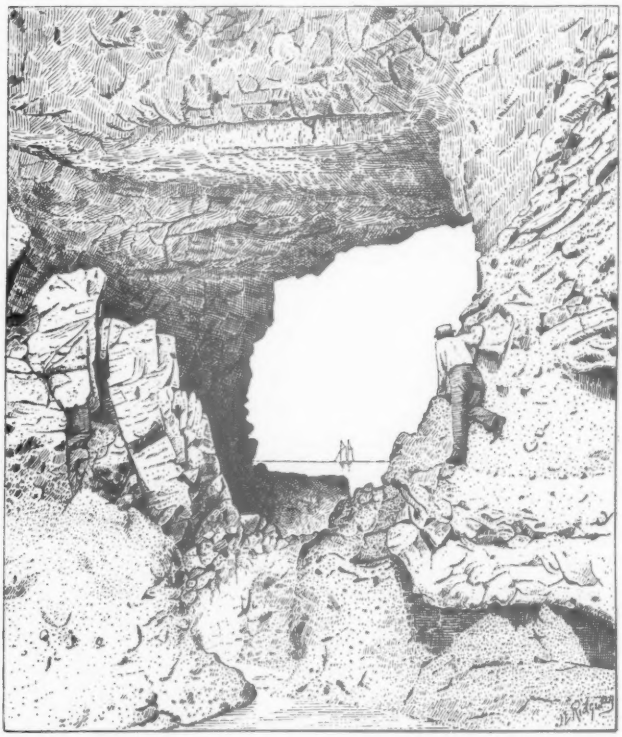


The Portão.

of dark brown basaltic tuff which here form the greater part of the strata of the island, until there remains little more than a narrow neck of steep and rugged cliffs, some of them eighty meters high, at whose breccia-covered foot breaks a ceaseless and violent surf. At one place an opening or tunnel has penetrated the isthmus; and this is the Portão Grande of the inhabitants of Fernando—"the hole in the wall" of English sailors.

The Portão beds of tuff (No. 54) are more homogeneous than those at Capim Azul. The individual fragments into which it breaks upon disintegration are seldom more than two inches in diameter, and the weathered surface of the beds has a lumpy rough appearance. The beds are regularly stratified, the dark brown material being streaked with lighter and darker bands. They dip southwest and southeast at an angle of nearly 45°, the opening being cut in a kind of syncline whose axis dips to the south. Overlying the tuff is a bed of hard rock containing many rectangular crystals, specimens of which unfortunately have not been preserved. This hard but much jointed rock fills the little depression, or syncline, in the tuff, and forms a nearly horizontal roof for this natural tunnel. The triangular gap between the tuff and its overlying bed is filled with irregularly stratified fragments which could not be examined.

The rock walls of the Portão from one face to the other are a little less than one hundred feet in thickness; the roof is about forty feet above the water at mean tide, and the opening is about forty feet in width. At the time of my visit the water did not have free passage through the opening, the northern entrance being barred by a narrow dyke of very hard basalt, about fifteen feet high, traversing the tuff and standing nearly square across its front.

The process by which the great opening has been made beneath this isthmus is not without interest. The surf about the Sapato is always violent, and especially so upon its south side. The excavation has all been done upon this south side, the character and dip of the rocks contributing largely to the result. If the waves breaking against the southwest dip of the excavated rock were carried up its slope, they were promptly checked by the hard overlying rock which forms the tunnel's roof. When, in the course of time, the wall was pierced, the waves struck the small basaltic dyke referred to above and this has ever since barred their progress. A gap, however, has been made through this dyke where it receives the full force of the waves. The dip of the dyke is toward the south and when the incoming waves plunge through the opening they strike this wall and are thrown off at a tangent, leap high in the air and fall in overwhelming volume and in spray upon the shingle of the northern beach. The swells and less violent waves occasionally lift their great volumes of water and pour intermittent cataracts over the gap on the little dyke, and down the channel which is opened to the left through the tuff between the wall and the overhanging cliffs.

The lowest beds exposed at the extreme western end of the Sapato are of basaltic tuff. The rock is reddish brown, soft and somewhat granular and contains an abundance of included frag-

ments of a great variety of other rocks. The sea has carved out at the base of its cliffs a beautiful and regular bench from twenty to forty feet in width, which runs across the whole western end of the Sapato midway between high and low tides. The beds here dip westward at an angle of about 25 degrees. At the northwestern corner of this exposure a stratum of compact rock (basalt?) about fifteen feet in thickness overlies the tuff and dips 40° to the eastward. Above this is a bed of very hard but much shattered rock which continues to and beyond the Portão of which it forms the roof.

Basaltic tuffs, very similar to or perhaps identical with those in which the Portão opening is excavated continue along the north shore of the island for at least half a mile east of the Portão. The cliffs of this material are usually vertical and capped by a bed of some more resisting rock From the promontory called Portãozinho, looking northeast along the trend of the island's north coast, one sees rising abruptly from the water a lofty vertical cliff of what appears to be rudely columnar basalt. This exposure was not examined near at hand. Both east and west of this exposure are others of reddish brown rocks resembling in general appearance, and at a distance, the soft reddish palagonite of Barro Vermelho (No. 62). The cliffs of this material have their bases deeply underscored by wave action.

Calcareous sandstone.—Besides the rocks of igneous origin, a calcareous sandstone occurs along some shores. It covers about one-third of Ilha Rapta, a part of São José, and small areas of the main island near the Lancha on the northeast, the high shore west of Atalaia Grande, the shore along the southwest side of the Sueste Bay, and forms Ilha Raza, Ilha do Meio and the Chapeo at the mouth of Bahia do Sueste. The material of the sand-rocks was originally deposited in the form of sand dunes and the bedding shows that it must have been blown by the winds chiefly from a southern or southeastern direction. The deposits are all on eastern or southeastern shores and have no connection with the existing beach. On Ilha Raza, it makes a perpendicular bluff forty feet or more in height; on Ilha Rapta it rises about forty feet above the water, while south of Atalaia Grande it stands at an elevation of at least a hundred feet above the sea. A microscopic examination shows that it has been consolidated by the deposit of lime carbonate dissolved from the uppermost layers by the waters of the rains aided possibly by the spray of the surf. The grains are fragments of shells, corals, sea urchins, foraminifers and other calcareous growths of the shores.

Where these sandstones rise from the ocean, as they do on Ilha do Meio, Ilha Raza, Ilha Rapta and Chapeo, the wind

MAP
of
FERNANDO DE NORONHA
BY
JOHN C. BRANNER
Recent Sandstones
12° 50'
3° 50'
3° 50' S.
Ponta da Cajagada
Espigão
Ponta do Norte
Ilha Rapta
Narcozinho
Ponta Negra
Furna
Ilha do Meio
São José
Sella á Cincta
M. Redondo
Pedra Furada
Ilha Raza
Bahia de Sto Antonio
Lancha
Morro dos Remedios
Pedra da Conceicão
Cuveira
Villagem
Dois Irmãos
Boldró
Pedra do Bode
Peak
Morro Francez
Espigões
O Xanxo
Samba Quixaba
Mulunguzinha
M. do Meio
Pontinha
Casão
Pedra Alta
Atalaia Grande
Dois Arabraços
Morro do Frade
Portãozinho
Atalainha
Sapato
Bahia do Sueste
Cabelludo
Morro Branco
Ilha de Ovos
Portão
Chapeo
Morro do Sueste
Peciença
Viração
Os Leões
Barro Vermelho
Capim Azul
Laja
Pontal
Scale
0
½
1
2 Miles
Longitude E. of Rio de Janeiro

Ponta da Cajagada
Ponta do Norte
Espigão
Ilha Rapta
Xareozinho
Ponta Negra
Ilha do Meio
São José
Sella á Cincta
Ilha Raza
Bahia de
Lancha
3° 50' S
Cayeira
Morro Francez
Espigões
Pontinha
Casão
Pedra Alta
Morro do Frade
Cabelludo
Ilha de Ovos
Scale
2 Miles

bedding is found to extend beneath the water,* indicating that the island once stood at a higher elevation. It should be noted, however, that the isolated remnant of sandstone near São José known as the Chapeo, and the western ends of Ilha Raza and Ilha Rapta stand upon waterworn shingle. Inasmuch as the cobbles must have been worn before they were covered by sand, the island must have stood at a level as low or somewhat lower than its present one while the cobbles were being made, and as the wind bedding could not be produced below the surface of the water or in sand to which the waves had access, the island must have been elevated somewhat before the dunes were blown over and deposited upon the shingle-covered beaches.

That they were blown up from the south or southeast is shown by the geographic positions of the various beds, by the absence of such rocks at corresponding elevations on the opposite sides of the islands, and by the internal structure of the rocks themselves, the steeper face of the dune always being toward the north or northeast. But as there is now no beach from which this sand could have been derived, we must conclude that the island was, not long ago, wider to the southeast, and that there were upon that side of it sandy shores, upon which an abundance of organic remains was thrown and ground to sand. These sands were then blown across the island to and upon the opposite shore, burying the former bowlder-covered beach near São José beneath 15 or 20 feet of sand, and piling it up considerably higher than the highest parts of the existing sand-rock. They joined into one what are now the separate islands and places marked as sandstone upon the map.

* See also the voyage of the Challenger, by Sir C. Wyville Thomson, vol. ii, p. 100. et seq.

Note upon the Map.—The names given upon the map and in this paper are those used by the inhabitants of the island. Other names have been used by visitors and navigators, especially by English and French-speaking persons who knew but little or nothing of the Portuguese language, or who have had no opportunity of learning the correct names. Inasmuch as these English and French names are not the ones known and used at Fernando de Noronha they cannot be regarded as correct That there may be no misunderstanding, however, about some of the more important points mentioned in this paper and by others who have visited this island, I give a few of the names erroneously used with the correct Portuguese names.

Ilha Rapta has been called *Rat Island* by the English, and *Ile aux Rats* by the French. The word *rapta* is the participle of the verb *raptar*, Eng. *rape*. It is supposed to have been given on account of the place once having been occupied by Dutch pirates.

Sella à Gineta (horned saddle), so named on account of its resemblance to a horned saddle, is called St. Michael's Mount by English and French.

Morro do Frade (friar's hill), so called on account of its resemblance to a monk's cowl, is called *Le Clocher* by the French. *Ilha Raza* (flat island), has been named Egg Island, and *Ilha do Meio* (middle island), has been called Booby Island.

Miscellaneous Scientific Intelligence.

1. *American Geological Society.*— The American Geological Society was formally organized at Ithaca, N. Y., on December 27th, 1888. The report of the Committee of Organization showed that 98 Geologists belonging to the American Association for the Advancement of Science had become Original Fellows; and that ballots received from 74 Fellows had elected the 17 candidates for admission to the Society. The names of 19 new candidates were presented and were referred to the Executive Council.

A committee was appointed to prepare a permanent Constitution; and another to take into consideration the whole matter of publications; both committees to report at the next meeting of the Society.

The officers for 1889 are: President, James Hall; 1st Vice-President, James D. Dana; 2nd Vice-President, Alex. Winchell; Secretary, John J. Stevenson; Treasurer, Henry S. Williams; Members of the Council, John S. Newberry, J. W. Powell, Chas. H. Hitchcock.

The Society adjourned to meet in Toronto on Wednesday, in August, 1889, immediately after the adjournment of Section E of the American Association for the Advancement of Science.

We are indebted for the above notes to the Secretary of the Society, Prof. J. J. Stevenson.

The Society, thus auspiciously inaugurated, promises, through the free interchange of views it will promote and in other ways, to be of great service to American Geology. No better choice for the position of President could have been made. Professor Hall began his labors early in the thirties, and, ever since, geology and paleontology have had his undivided attention. His works—making more than a dozen great volumes with over 700 plates of fossils—have laid the foundations of American Geology, and have been a chief source of its progress. J. D. D.

2. *Mineral Resources of the United States;* calendar year, 1887, David T. Day, Chief of division of Mining Statistics and Technology. 832 pp. 8vo. Washington, 1887 (U. S. Geol. Survey).—This, the fifth volume of the series, appears with most commendable promptness, and contains the usual large amount of valuable information in regard to the development of the mineral interests of the country during the calendar year 1887. The tabulated list of useful minerals, arranged according to states and territories, has been much improved by additions and general revision; this work has been in the hands of Albert Williams, Jr.

3. *Index der Krystallformen der Mineralien* von Dr. Victor Goldschmidt. Vol. II, Part 4, vol. III, Parts 2 and 3.—This continuation of Goldschmidt's important work on crystallography (see xxxi, 475; xxxii, 485; xxxv, 501) embraces the species, alphabetically arranged, from idocrase to kupfervitriol, and ralstonite to syngenite. The same exhaustive thoroughness is shown in these parts as in those before issued.

APPENDIX.

ART. XVIII.—*Restoration of Brontops robustus, from the Miocene of America;* * by Professor O. C. MARSH. (With Plate VI.)

THE largest mammals of the American Miocene were the huge *Brontotheridæ*, which lived in great numbers on the eastern flanks of the Rocky Mountains, and were entombed in the fresh-water lakes of that region. They were larger than the *Dinocerata* of the Eocene, and nearly equalled in size the existing elephant. They constitute a distinct family of perissodactyles, and were more nearly allied to the rhinoceros than to any other living forms.

The deposits in which their remains are found have been called by the author, the Brontotherium beds. They form a well-marked horizon at the base of the Miocene. These deposits are several hundred feet in thickness, and may be separated into different subdivisions, each marked by distinct genera or species of these gigantic mammals.

The author has made extensive explorations of these Miocene lake-basins, and has secured the remains of several hundred individuals of the *Brontotheridæ*, which will be fully described in a monograph, now well advanced towards completion, to be published by the United States Geological Survey. The atlas of sixty lithographic plates is already printed, and the author submitted a copy to the section. The last plate of this volume is devoted to a restoration of *Brontops robustus*, one-seventh natural size, and a diagram enlarged from this plate to natural size was also exhibited.†

* Abstract of a paper read before Section D, of the British Association for the Advancement of Science, at the Bath meeting, Sept. 7th, 1888.

† The present plate (VI), one twenty-fourth natural size, shows a reduced copy of the same restoration.

The skeleton represented in this restoration is by far the most complete of any of the group yet discovered. It was found by the author in Dakota, in 1874, and portions of it have been exhumed at different times since, some of the feet bones having been recovered during the past year. It is a typical example of the family, and shows well the characteristic features of the genus and species which it represents.

The most striking feature of the restoration here given, aside from the great size of the animal, is the skull. This is surmounted in front by a pair of massive prominences, or horn-cores, which are situated mainly on the frontal bones. The nasals contribute somewhat to their base, in front, and the maxillaries support the outer face. These elevations, or horn-cores, vary much in size and shape in the different genera and species. They are always very small in the females.

The general form of the skull and lower jaw is well shown in the figure. The prominent occipital crest, the widely-expanded zygomatic arches, and the projecting angle of the lower jaw, are all characteristic features. In general shape, the skull resembles that of *Brontotherium*, but may be readily distinguished from it by the dental formula, which is as follows:

Incisors $\frac{2}{1}$; canines $\frac{1}{1}$; premolars $\frac{4}{4}$; molars $\frac{3}{3}$.

The presence of four premolars in each ramus of the lower jaw is a distinctive feature in this genus. This character, with the single, well-developed lower incisor, marks both the known species.

The number of teeth varies in the different genera. The form of the teeth, especially in the molar series, is more like that in *Chalicotherium* and *Diplacodon* than in any other known forms. The teeth in the allied genus *Brontotherium* have already been figured and described by the author.

The vertebræ are somewhat similar to those of the existing rhinoceros. In the present genus, *Brontops*, the neural spines of the dorsal vertebræ are elevated and massive. There are four sacral vertebræ in this genus, and in the known species the tail is short and slender, as in the individual here described.

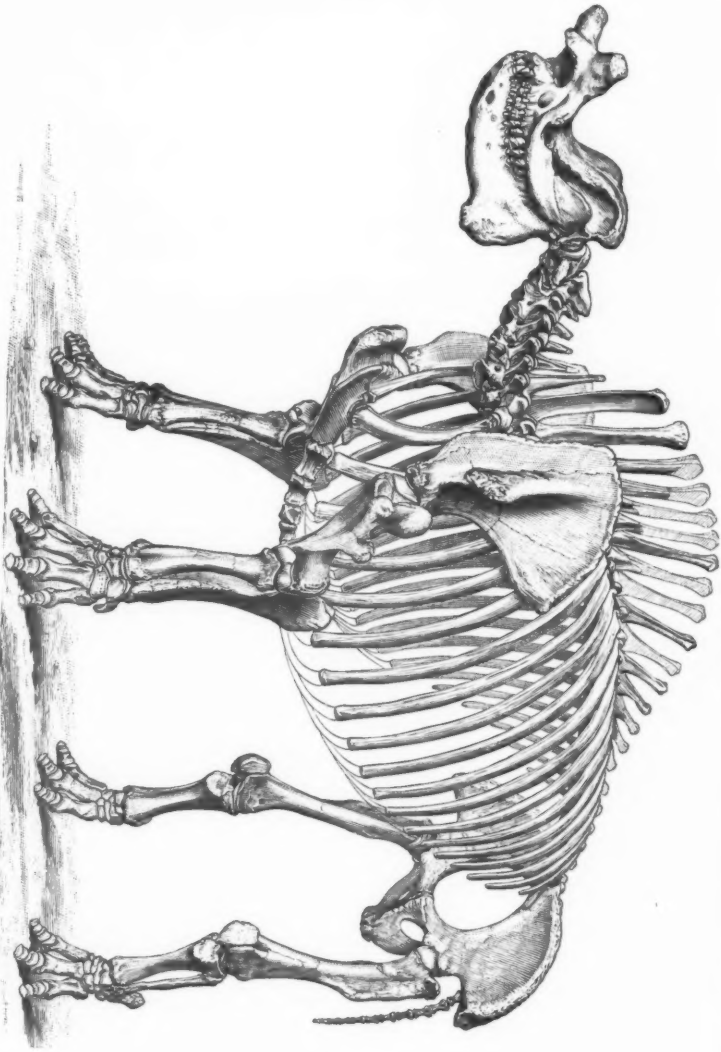
The ribs are strong and massive. The sternal bones are compressed transversely. The exact form of the first one is not known with certainty, and is here restored from the rhinoceros. This is the only important point left undetermined in the restoration.

The fore limbs are especially robust. The humerus has its tuberosities and ridges very strongly developed, and the radius and ulna have their axes nearly parallel. There are four well-developed digits in the manus, the first being entirely wanting.

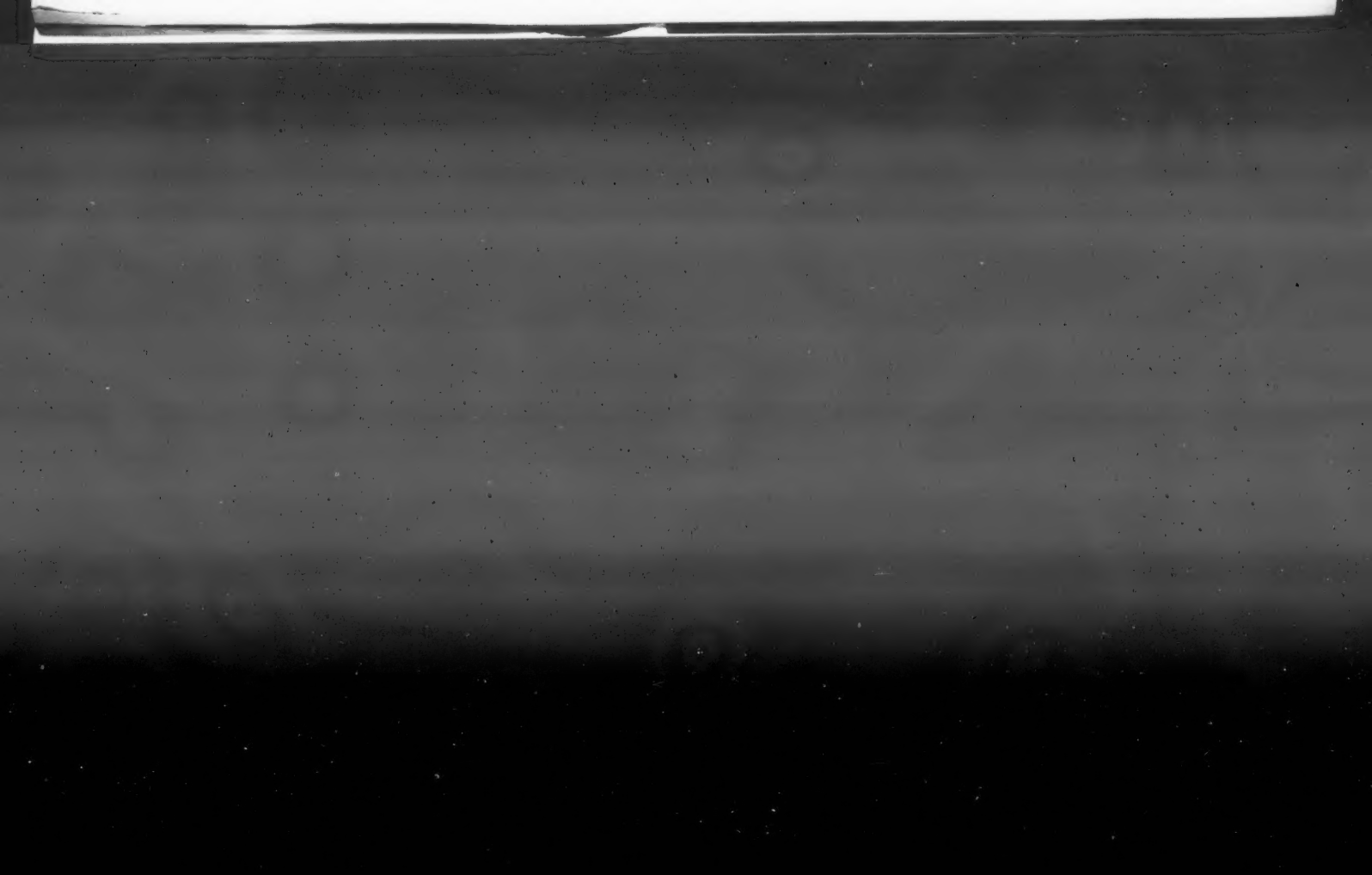
The pelvis is very wide, and transversely expanded, as in the elephant. The femur is long, and has the third trochanter rudimentary. The tibia and fibula are quite short. The calcaneum is very long, and the astragalus is grooved above. There are only three digits in the pes, the first and fifth having entirely disappeared.

Diplacodon of the Upper Eocene is clearly an immediate ancestor of the *Brontotheridæ*, while *Palæosyops* and *Limnohyus* of the Middle Eocene are on the more remote ancestral line. The nearest related European form is the Miocene *Chalicotherium*. No descendents of the *Brontotheridæ* are known.

Menodus, *Megacerops*, *Brontotherium*, *Symborodon*, *Menops*, *Titanops*, and *Allops*, all belong to the family *Brontotheridæ*, and their relation to the genus here described, and to each other, will be fully discussed in the monograph, to which reference has already been made.



Restoration of BRONTOPS ROBUSTUS, Marsh.; one twenty-fourth natural size.



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